

# HANDBOOK OF CHEMISTRY,

FOR

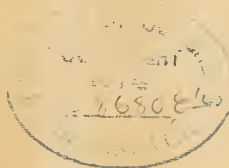
SCHOOL AND HOME USE.

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*By the same Authors,*

HANDBOOK OF NATURAL PHILOSOPHY.  
HANDBOOK OF THE STARS.

These are elementary manuals of Natural Philosophy and Astronomy, on the same plan as this book. In each of the three, the more difficult and theoretical portions of the subject are treated in the Appendix.

*Also,*

THE CAMBRIDGE COURSE OF PHYSICS,

IN THREE VOLUMES :

- I. CHEMISTRY.
- II. NATURAL PHILOSOPHY.
- III. ASTRONOMY.

B.74

## PREFACE

TO SECOND EDITION.

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WE have prepared this book at the urgent request of many teachers who desire something easier and briefer than the "Chemistry" of the Cambridge Course of Physics. This is a more elementary work, and therefore less theoretical. It is, in a word, a manual of the elementary facts and principles of Chemistry. While there is little that is strictly theoretical in the body of the book, we have not forgotten that Chemistry is not a mere mass of dead facts, but a living science. We have therefore aimed to present the facts in such a way as to awaken a love for the science itself, no less than to show its utility. Our object has been not only to describe the properties of the leading elements and compounds, but also to show the wonderful part played by the chemical force in nature, as well as to illustrate its practical applications in the arts. We have endeavored to give the young student a glimpse of—

—— "the circle of eternal change,  
Which is the life of nature,"—

a life whose fountain-head is the sun, and whose



processes we trace in the chemistry of the atmosphere. In this indirect but natural way, we have introduced as much of *organic* chemistry as could well find place in an elementary manual.

The *metals* we have grouped more according to their uses than according to their chemical relations, with a view to make the subject less dry and more practical.

It is difficult to write a book suited to the wants of different schools, or even of successive classes in the same school; since the schools vary in grade, and the classes in ability. We have attempted to meet this difficulty by putting into the body of the book the simpler and more practical portions of the subject, which can be readily mastered by young pupils of average ability, and by adding in the Appendix an outline of some of the more important principles of chemical philosophy. In this way, the simpler and the more difficult parts, instead of being confusedly mixed together, distinguished merely by the common and clumsy expedient of coarse and fine print, are treated separately, so that each may be complete in itself. At the same time, the two parts do not overlap, but form successive chapters progressively arranged. Our experience as teachers has convinced us, that this is, on the whole, the best method of meeting the wants of successive classes; and the marked favor with which our "Handbook of the Stars," an elementary "Astronomy" on precisely the same

plan, has been received, shows that the experience of many of our fellow-teachers has been pretty much the same as our own.

We have not forgotten that the theories of chemistry have been revolutionized within a few years; and we have of course used the new symbols and notation, without which it is as impossible to teach modern chemistry as it would be to teach modern astronomy in the language of the old astrologers. Until within a year or two, there was some excuse for clinging to the old notation, as rival systems were contending for the supremacy. But even as long ago as October, 1866, Miller, the first English authority on the subject, wrote as follows: "The change in notation is certain to be adopted, since in none of the recent investigations in this country, and in very few of those on the Continent, is the old method made use of." Since that time, the system of symbols and notation used by us in this book has been formally adopted by the Chemical Society of London, whose decision is recognized as law in England; and it is now taught in Harvard College, which will certainly be acknowledged as one of the highest authorities in this country.


In the chapter on the Chemistry of the Atmosphere, we have been especially indebted to the Lectures on "Religion and Chemistry" (New York, 1866), by Professor Josiah P. Cooke, Jr., of Harvard College; and in the chapters on Quantivalence and Molecular Structure, in the Appendix, we have

drawn freely from the "First Principles of Chemical Philosophy" (Cambridge, 1868), by the same eminent author. His remarkable power of presenting difficult subjects in a way at once clear and attractive, makes these books especially valuable to the teacher.

We have been under obligations, also, to Miller's "Elements of Chemistry" (London, 1866), and Roscoe's "Elementary Chemistry" (*New Edition*, London and New York, 1869). These books, as well as Hofmann's "Modern Chemistry" (London, 1865), and Wurtz's "Introduction to Chemical Philosophy" (London, 1867), the teacher will find useful for purposes of reference.

CAMBRIDGE, January 1, 1870.

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 Teachers will observe that, except in the Appendix, either the old chemical name or the ordinary commercial name of the substance is generally added, in parentheses, to the new chemical name.

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HANDBOOK OF CHEMISTRY.





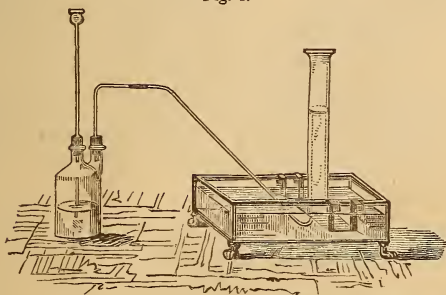
## THE NON-METALLIC ELEMENTS.

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### COMPOUNDS AND ELEMENTS.

1. *Muriatic Acid*. — Into a bottle arranged as shown in Figure 1, put a few bits of zinc, and pour a little muriatic acid over them. Effervescence at once takes place, and a colorless gas passes through the bent tube into the jar, which has been previously filled with water, and in-

Fig. 1.

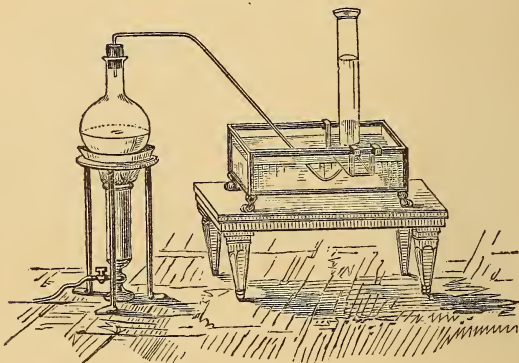


verted over the trough. When the jar is full of gas, raise it from the water, and apply a lighted taper to its mouth. The gas takes fire with a slight explosion, and burns with a pale flame. This gas is called *hydrogen*, and comes from the muriatic acid.

Pour a little of the muriatic acid into a flask (Figure 2), add a little black oxide of manganese, mix them thor-

oughly, and heat gently. A greenish-yellow gas passes into the jar inverted over the water-trough. When the jar is full, close its mouth with a glass plate, remove it from the trough, and set it on the table. Moisten a piece of litmus-paper or colored cotton cloth, and hold it inside the jar. It will be instantly bleached. This gas is called *chlorine*, and, like the hydrogen, comes from the muri-

Fig. 2.



atic acid. Chlorine may be recognized by its bleaching power, and also by its color and its suffocating odor.

We have now got from muriatic acid two gases, hydrogen and chlorine.

If a small glass jar be filled with equal parts of these two gases, and a light be applied to its mouth, the mixture will take fire with an explosion. If a little dish of ammonia be standing by, a dense white cloud will appear when the gases burn.

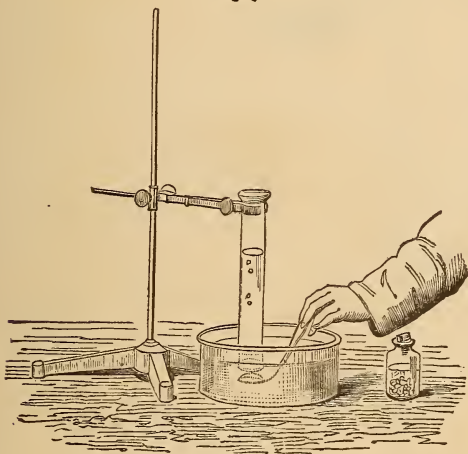
Now this cloud shows that muriatic acid has been produced; for, if we dip a glass rod in muriatic acid, and hold it over the ammonia, the white cloud at once appears.

Muriatic acid, then, contains nothing but hydrogen and chlorine.

2. *Water*.—If a bit of sodium be thrust beneath the mouth of an inverted jar, filled with water, as shown in Figure 3, bubbles of gas rise and fill the jar. On raising the jar, and applying a taper to its mouth, we see, by the way in which the gas takes fire, that it is hydrogen.

Fill a tall glass jar with *chlorine water* (that is, water which has absorbed chlorine gas), invert it, with its

Fig. 3.

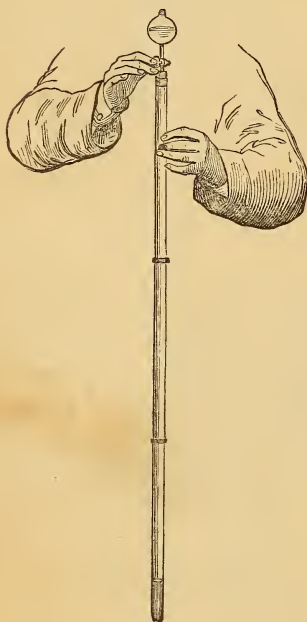


mouth in a shallow dish of water, and leave it for ten or twelve hours in the sunshine. Bubbles of gas will be seen to rise, and collect in the top of the jar. If now we set the jar upright, and plunge a lighted taper into the gas, the taper burns much more brightly than in the air. This gas is called *oxygen*.

We have thus got hydrogen and oxygen from water. If, now, we burn a jet of hydrogen in a jar of oxygen, moisture will collect on the sides. This moisture is water, and comes from the union of the hydrogen and the oxygen. This shows that there is nothing but oxygen and hydrogen in water.

3. *Ammonia*.—Fill with chlorine a long glass tube,

Fig. 4.



closed at one end. Close the other end with a cork, through which passes a dropping tube. (Figure 4.) If, now, a little ammonia be dropped into the tube, flashes of light and dense white fumes appear within. Next allow water to run into the tube as long as it will, and test the gas which remains, by putting a piece of litmus-paper into it. The paper is not bleached, hence the gas is not chlorine. Plunge a lighted taper into it, and it goes out, and the gas does not take fire; hence the gas is neither oxygen nor hydrogen. It is *nitrogen*, and it always, as in this case, extinguishes a lighted taper.

This nitrogen must have come from the ammonia, since there was no nitrogen in the water poured into the tube.

The white fumes which appeared in the tube, when the ammonia was dropped in, showed that muriatic acid was formed. Now we have learned that muriatic acid is made up of chlorine and hydrogen. The hydrogen must also have come from the ammonia.

Ammonia, then, contains nitrogen and hydrogen. It has been found by experiment that it contains nothing but these two gases.

4. *Compounds and Elements*.—We have now seen that muriatic acid, water, and ammonia, are made up of

other substances, which we can separate from them. In other words, they are *compound* substances, and we have *decomposed* them. But no means has been found of decomposing oxygen, hydrogen, chlorine, and nitrogen into simpler substances. These, and other substances which cannot be decomposed, are called *elements*.

Most substances with which we are familiar are compounds. The metals, however, are all elements.

There are only about sixty-five elements in all, and many of these are very rare substances.

5. *Names and Symbols of Elements.*—Elements have been divided into two classes, *metallic* and *non-metallic*. The following list contains the names of the most important elements usually put in each class, together with the abbreviations of these names commonly used. These abbreviations are called *symbols*.

#### NON-METALLIC ELEMENTS.

NAME.	SYMBOL.	ATOMIC WEIGHT.	NAME.	SYMBOL.	ATOMIC WEIGHT.
Boron	B	11	Iodine	I	127
Bromine	Br	80	Nitrogen	N	14
Carbon	C	12	Oxygen	O	16
Chlorine	Cl	35.5	Phosphorus	P	31
Fluorine	F	19	Silicon	Si	28
Hydrogen	H	1	Sulphur	S	32

2

#### METALLIC ELEMENTS.

Aluminium	Al	27.4	Magnesium	Mg	24
Antimony ( <i>stibium</i> )	Sb	122	Manganese	Mn	55
Arsenic	As	75	Mercury ( <i>hydrargyrum</i> )	Hg	200
Barium	Ba	137	Nickel	Ni	58.7
Bismuth	Bi	210	Platinum	Pt	197.5
Calcium	Ca	40	Potassium ( <i>kalium</i> )	K	39
Chromium	Cr	52.5	Silver ( <i>argentum</i> )	Ag	108
Cobalt	Co	58.7	Sodium ( <i>natrium</i> )	Na	23
Copper ( <i>cuprum</i> )	Cu	63.5	Strontium	Sr	87.5
Gold ( <i>aurum</i> )	Au	197	Tin ( <i>stannum</i> )	Sn	118
Iron ( <i>ferrum</i> )	Fe	56	Zinc	Zn	65.2
Lead ( <i>plumbum</i> )	Pb	207			

3

It will be noticed that in some cases the symbol is an abbreviation of the *Latin* name of the element.

6. *Affinity*.—The force which draws elements together, and locks them up in compounds, is called *affinity*, or *chemical force*.

One of the characteristics of this force is, that *it changes the properties of the substances which it brings together*. It not only unites different substances, but unites them so as to form a new substance. It *combines* them.

This characteristic is well illustrated in the case of water, a substance wholly unlike hydrogen, which is combustible, and oxygen, which aids combustion.

The second characteristic of affinity is, that *it always acts between definite quantities of matter*. This may be illustrated by the following experiment:—

Partially fill the closed arm of the U tube (Figure 5)

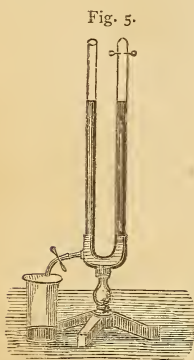


Fig. 5.

with a mixture of hydrogen and oxygen, using more than twice as much hydrogen as oxygen. Explode the mixture by means of an electric spark from a Leyden jar. The hydrogen and the oxygen combine to form water, but some gas remains, which, if tested with a taper, is found to be hydrogen.

If now we put into the tube a mixture containing *less* than twice as much hydrogen as oxygen, the gas which remains after the explosion is found to be oxygen.

In both cases, the oxygen combines with exactly twice its bulk of hydrogen, and this will be true in whatever proportions the gases may be mixed.

This experiment also illustrates the *third* characteristic of affinity, which is, that *it is often dormant until it is roused to activity by heat, or some other force*. The



oxygen and the hydrogen showed no disposition to combine until the spark was sent through them.

7. *Molecules and Atoms*.—It is supposed that all bodies are made up of small particles called *molecules*, and that these molecules are made up of smaller particles, which are called *atoms* (that is, *not to be divided*), since we are not able to subdivide them.

In an elementary substance, the atoms are supposed to be all alike in form and weight, but those of one element differ in weight from those of another. In a *compound* substance, the *molecules* are supposed to be alike, each being made up of a fixed number of atoms of each of the component elements; but the molecules of one compound differ from those of another in their atomic constitution. This theory of the composition of substances is called the *atomic theory*.

Thus the molecules of *muriatic acid* are supposed to be made up of *one* atom of hydrogen and *one* of chlorine; the molecules of *water* to be made up of *two* atoms of hydrogen and *one* of oxygen; and the molecules of *ammonia* to be made up of *three* atoms of hydrogen and *one* of nitrogen.

8. *Symbols of Compounds*.—The symbol of a compound is made up of the symbols of its elements. It also indicates the atomic constitution of the molecules of the compound. The symbol of each element represents *one atom* of that element. If there is more than one atom of the element in the molecule, this is indicated by a small figure placed at the right of the symbol. Thus the symbol for *muriatic acid* is  $\text{HCl}$ ; indicating that muriatic acid is a compound of hydrogen and chlorine, and that a molecule of muriatic acid is made up of one atom of hydrogen and one of chlorine. The symbol for *water* is  $\text{H}_2\text{O}$ , since water is a compound, whose molecule contains two atoms of hydrogen and one of oxygen. The



symbol of *ammonia* is  $\text{H}_3\text{N}$ , its molecule being made up of three atoms of hydrogen and one of nitrogen.

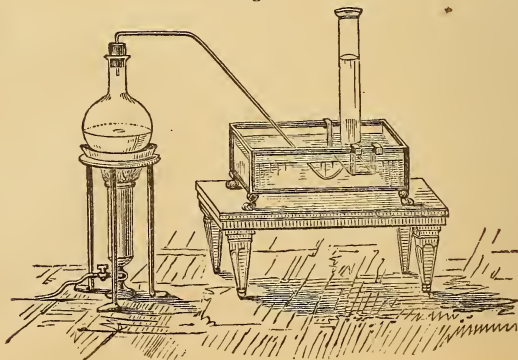
9. *Atomic Weights*. — According to the atomic theory, an atom of chlorine weighs 35.5 times as much as an atom of hydrogen; an atom of oxygen weighs 16 times as much as one of hydrogen; and an atom of nitrogen 14 times as much as one of hydrogen. If then we represent the weight of an atom of hydrogen by 1, the weight of an atom of chlorine will be 35.5; that of an atom of oxygen, 16; and that of an atom of nitrogen, 14. These numbers are called the *atomic weights* of these elements. (5.)

We now see that the symbol of a compound represents not merely the atomic constitution of the compound, but also the relative weights of its elements. Thus *muratic acid*,  $\text{HCl}$ , contains 1 part by weight of hydrogen to 35.5 parts by weight of chlorine; *water*,  $\text{H}_2\text{O}$ , contains 2 parts by weight of hydrogen to 16 of oxygen; and *ammonia*,  $\text{H}_3\text{N}$ , contains 3 parts by weight of hydrogen to 14 of nitrogen.

## OXYGEN.

10. *Preparation of Oxygen*. — Oxygen is most readily obtained from potassic chlorate (chlorate of potash), a substance of whose weight it forms about 40 per cent. The chlorate is heated in a flask (Figure 6), and the gas is

Fig. 6.



collected over water. Potassic chlorate is a compound of chlorine, potassium, and oxygen, and its symbol is  $\text{KClO}_3$ . The oxygen is set free by the heat, leaving the chlorine and potassium as a compound called *potassic chloride*.

A chemical change of this kind is called a *reaction*, and may be expressed in the form of an equation. In this case the equation will be —



indicating that the potassic chlorate,  $\text{KClO}_3$ , has been broken up into potassic chloride,  $\text{KCl}$ , and oxygen,  $\text{O}$ .

If a small quantity of black oxide of manganese be mixed with the potassic chlorate, the gas is given off at a much lower temperature, and more gradually. The manganese, however, undergoes no change in the process.

11. *Properties of Oxygen*.—We have already seen (2) that a taper burns much more vividly in oxygen than in the air.

If a piece of charcoal be lighted and plunged into a jar of oxygen, it burns with a very brilliant white light. Pour now some clear lime-water into the jar, and shake it. The liquid becomes milky white, showing that the gas has undergone a change; for oxygen has no effect upon lime-water. Charcoal is a form of the element *carbon*, and the oxygen has combined with it. The compound produced is called *carbonic anhydride* (*carbonic acid*), and its composition is represented by the symbol,  $\text{CO}_2$ .

If a bit of sulphur be ignited and put into a jar of oxygen, it burns with a vivid blue light and a suffocating odor. The sulphur and the oxygen have combined to form *sulphurous anhydride* (*sulphurous acid*), the symbol of which is  $\text{SO}_2$ .

Phosphorus burns in oxygen with dazzling brilliancy, producing dense, white fumes of *phosphoric anhydride* (*phosphoric acid*),  $\text{P}_2\text{O}_5$ .

Thus far, we have found that substances which burn in the air burn more rapidly and more brightly in oxygen. If, now, we fasten a bit of wood to a steel watch-spring, ignite the wood, and plunge the whole into a jar of oxygen, the watch-spring takes fire, and burns as readily as a splint of wood burns in the air. In this case the iron and the oxygen combine, forming a mixture of two oxides of iron,  $\text{FeO}$ , *ferrous oxide*, and  $\text{Fe}_2\text{O}_3$ , *ferric oxide*.

The above experiments illustrate several properties of oxygen: (1) the *passive state in which it exists under ordinary circumstances*, it being necessary to *heat* it in order to make it combine rapidly with any substance; (2) the *intense energy with which it enters into combination when once aroused*; and (3) the *wide range of its affinities*. It combines with every known element, except fluorine.

12. *Ozone*.—If a series of electric sparks be sent through dry oxygen, the gas undergoes a change. It acquires more active properties and a peculiar odor from which it takes its name, *ozone*.\* The odor perceived when an electrical machine is worked is owing to the presence of ozone.

If a paper moistened with a solution of *potassic iodide* (*iodide of potassium*),  $\text{KI}$ , and starch paste be held opposite a point on the conductor of an electrical machine, the paper becomes blue. The iodine is set free by the ozone, and unites with the starch, forming a blue compound, which colors the paper. Ordinary oxygen has no such power to separate iodine from its combination with potassium.

There has been much discussion concerning the nature of ozone. It appears, however, to be simply oxygen in a modified and condensed form.

\* *Ozone* is derived from a Greek word which means *to emit a bad odor*.

This *partially* active state of oxygen is intermediate between the active and passive states already mentioned.

13. *Allotropic States*. — There are other elements which exist in states in which their properties are as unlike as those of oxygen and ozone. These different states of an element are called *allotropic* states.

14. *Oxides*. — “The simple compounds of the elements with oxygen are called oxides, and the specific names of the different oxides are formed by placing before the word *oxide* the name of the element, but changing the termination into *ic* or *ous*, to indicate different degrees of oxidation, and using the Latin name of the element in preference to the English, both for the sake of euphony and in order to secure more general agreement among different languages. When the same element unites with oxygen in more than two proportions, the Latin prepositions or numeral adverbs, *sub*, *per*, *bis*, etc., are prefixed to the word *oxide* in order to indicate the additional degrees. Formerly these compounds were called the oxides of the different elements, the degrees of oxidation being indicated solely by the prefixes.” \*

The ending *ous* indicates a lower degree of oxidation than the ending *ic*.

15. *Acids*. — Very many of the non-metallic oxides combine with *water*, forming compounds which turn blue litmus-paper red. Such oxides are called *acid oxides*, or *anhydrides*, and their compounds with water are called *acids*. Thus  $\text{SO}_2 + \text{H}_2\text{O} = \text{H}_2\text{SO}_3$ .  $\text{SO}_2$  is *sulphurous anhydride*, often improperly called *sulphurous acid*, a name which properly belongs to  $\text{H}_2\text{SO}_3$ . So  $\text{H}_2\text{O} + \text{SO}_3$  (*sulphuric anhydride*)  $= \text{H}_2\text{SO}_4$  (*sulphuric acid*).

Here, too, as in the case of oxides, the ending *ous* denotes a lower degree of oxidation than the ending *ic*.

\* First Principles of Chemical Philosophy. By Josiah P. Cooke, Jr., 1868, p. 69.

When more than two acids are formed by the same elements, the prefixes *hypo* (=less) and *hyper* or *per* (more) are used. Thus, hydrogen, chlorine, and oxygen form four acids:  $\text{HClO}$ , *hypochlorous acid*;  $\text{HClO}_2$ , *chlorous acid*;  $\text{HClO}_3$ , *chloric acid*; and  $\text{HClO}_4$ , *hyperchloric acid*, or *perchloric acid*.

Acids are often named from all their elements, thus: —

$\text{H}_2\text{SO}_3$ , <i>hydric sulphite</i> ;	$\text{HClO}_2$ , <i>hydric chlorite</i> ;
$\text{H}_2\text{SO}_4$ , <i>hydric sulphate</i> ;	$\text{HClO}_3$ , <i>hydric chlorate</i> ;
$\text{HClO}$ , <i>hydric hypochlorite</i> ;	$\text{HClO}_4$ , <i>hydric perchlorate</i> .

The endings *ite* and *ate* in these names indicate oxygen, and *ite* the less amount of this element.

16. *Bases*. — Many of the metallic oxides combine with water to form compounds whose properties are the opposite of those of the acids. These are called *basic oxides*, and their compounds with water are called *bases*.

Bases are named like acids, as shown above. Thus, —

$\frac{1}{2}(\text{K}_2\text{O}$ , *potassic oxide*,  $+\text{H}_2\text{O}) = \text{KHO}$ , *potassic hydrate*;  
 $\text{BaO}$ , *baric oxide*,  $+\text{H}_2\text{O} = \text{BaH}_2\text{O}_2$ , *baric hydrate*;  
 $\text{FeO}$ , *ferrous oxide*,  $+\text{H}_2\text{O} = \text{FeH}_2\text{O}_2$ , *ferrous hydrate*;  
 $\text{Fe}_2\text{O}_3$ , *ferric oxide*,  $+3\text{H}_2\text{O} = \text{Fe}_2\text{H}_6\text{O}_6$ , *ferric hydrate*.

The *potassic* and *sodic hydrates* ( $\text{KHO}$  and  $\text{NaHO}$ ) and some others are called *alkalies*.

17. *Neutrals*. — Oxides which, like water, are neither acid nor basic, are called *neutral oxides*, or *neutrals*.

18. *Salts*. — A metal may take the place of the hydrogen in an acid, and the compound thus formed is called a *salt*. Thus, the metal *potassium* may take the place of the hydrogen in  $\text{H}_2\text{SO}_3$  and  $\text{H}_2\text{SO}_4$ , forming the *salts*  $\text{K}_2\text{SO}_3$  and  $\text{K}_2\text{SO}_4$ .

Salts are named in the same way as the acids and bases already explained. Thus we have —

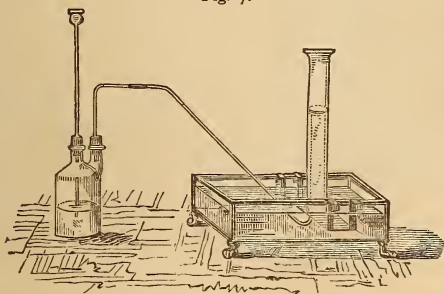
$\text{K}_2\text{SO}_3$ , <i>potassic sulphite</i> ;	$\text{FeSO}_4$ , <i>ferrous sulphate</i> ;
$\text{K}_2\text{SO}_4$ , <i>potassic sulphate</i> ;	$\text{Fe}_2\text{SO}_4$ , <i>ferric sulphate</i> ;
$\text{KNO}_3$ , <i>potassic nitrate</i> ;	$\text{KClO}_3$ , <i>potassic chlorate</i> .

19. *Binary and Ternary Compounds.* — Compounds like HCl (muriatic acid), FeO (ferrous oxide), KI (potassic iodide), etc., which contain *two* elements, are called *binary* compounds; and compounds like  $\text{H}_2\text{SO}_4$  (sulphuric acid), KHO (potassic hydrate),  $\text{FeSO}_4$  (ferrous sulphate), etc., which contain *three* elements, are called *ternary* compounds. (See Appendix, VII.)

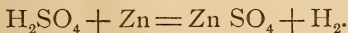
## HYDROGEN.

20. *Preparation of Hydrogen.* — The most convenient way of preparing hydrogen is by the action of zinc on dilute sulphuric acid. The apparatus required is shown in Figure 7.

Fig. 7.



The reaction between the zinc and the sulphuric acid is shown in the following equation:—



The zinc changes places with the hydrogen, forming the salt known as *zincic sulphate*, or *white vitriol*, while the hydrogen is set free.

21. *Properties of Hydrogen.* — If soap-bubbles are blown with a mixture of two measures of hydrogen to one of oxygen, they will explode violently when touched with a lighted taper; showing the intense energy with



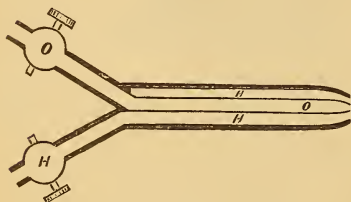
which hydrogen and oxygen combine at a high temperature. If a mixture of hydrogen and atmospheric air be used, a similar explosion will take place. Hence, in preparing hydrogen for experiments, great care must be taken to expel all air from the apparatus before any of the gas is collected.

If a small rubber balloon be filled with hydrogen, it rises readily in the air, showing that the gas is lighter than air. It is, in fact, the lightest substance known, being 14.5 times lighter than air, and 16 times lighter than oxygen. It was formerly used in filling balloons; but coal-gas, which, though not so light, is much cheaper, is now commonly employed instead.

The lightness of hydrogen and the energy with which it combines with oxygen, are its two most important characteristics.

22. *The Oxy-hydrogen Blowpipe.*—The energy with which hydrogen and oxygen combine develops intense heat. This may be shown by means of the *oxy-hydrogen blowpipe*, represented in Figure 8. The hydrogen is

Fig. 8.



forced through the tube *H*, and the oxygen through the tube *O*; and it will be seen that the two can mix only at the mouth of the jet where they are burned, so that there is no danger

of an explosion. The gases may be kept in a *gasometer* (Figure 9), or, more conveniently, in gas-bags of india-rubber.

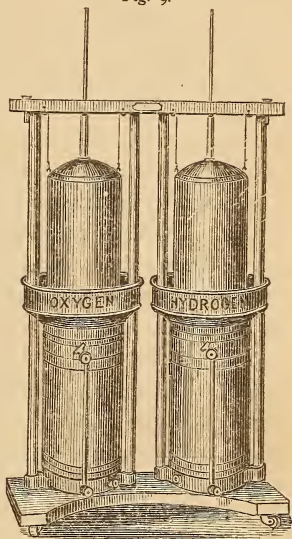
Hold a copper or iron wire in the flame of this blowpipe, and it burns as readily as a pine shaving held in the flame of a lamp. A steel watch-spring burns with brilliant scintillations. If a bit of zinc be placed on a



piece of charcoal hollowed out for the purpose, and the flame of the blowpipe be directed upon it, the metal quickly melts and burns. Antimony, bismuth, and many other metals will burn in the same way, each with a characteristic light. Cast-iron burns with a shower of bright sparks. Platinum, which is one of the most infusible of substances, is readily melted, and even converted into vapor.

A small cylinder of lime placed in the blowpipe flame becomes white-hot, and glows with most intense brilliancy, forming what is known as the *lime light* or *Drummond light*. When the rays of this light have been gathered and reflected by a mirror, it has been seen at a distance of one hundred miles in full daylight.

Fig. 9.



## WATER.

23. *The Properties of Water.* — The most important compound of hydrogen is *water*, which, as we have already learned<sup>a</sup> (2), contains hydrogen and oxygen.

At ordinary temperatures, water is a clear, colorless transparent liquid, without taste or smell. It freezes at  $32^{\circ}$ , and under the ordinary pressure of the atmosphere it boils at about  $212^{\circ}$ .

It is the most universal *solvent* known. There are but few substances which are not dissolved by it. Even those which we call insoluble, generally differ from the rest

only in degree. Spring water dissolves lime-rocks, and almost all other mineral substances. The beautiful crystals found in the rocks are almost invariably deposited from a solution of the mineral in water, though in many cases it may have taken thousands of years to form them.

Water dissolves almost all *gases* as well as solids. It is on the gases dissolved in the water that all aquatic plants and animals live.

24. *Various kinds of Natural Waters.*—Owing to its solvent powers, water is never found in nature in a state of purity. *Rain water*, collected after long-continued wet weather, comes nearest to it; but even this always contains small quantities of atmospheric air, and the gases floating in the air.

*Spring water* always contains more or less of saline matter, which it has dissolved from the soil. The salts most frequently found in it are common salt, calcic carbonate and sulphate (carbonate and sulphate of lime), and magnesian carbonate and sulphate (carbonate and sulphate of magnesia). Most spring water contains carbonic acid, to which it owes its sprightly taste.

*Mineral waters* are waters which contain an unusually large proportion of any of the salts just named, or of other and rarer substances. In many cases they have medicinal qualities, which vary with the salts held in solution. They sometimes contain salts of iron, and are then called *chalybeate* springs. In other instances, carbonic acid is so abundant as to give them an *effervescent* character. Less frequently *sulphur* is the chief ingredient, giving the water a nauseous taste and smell.

Water is familiarly called *hard* or *soft*, according to its action on soap. Hard waters contain salts of calcium or magnesium, which cause the soap to *curdle*, that is, to become insoluble. Soft waters do not contain these salts, and dissolve the soap without difficulty. Many hard

waters become soft by boiling, the salts held in solution being deposited, as a *fur* or crust, on the inside of the boiler.

*Sea water* contains a large amount of common salt and of magnesian chloride (chloride of magnesium), to which it owes its saline, bitter taste. Smaller quantities of many other salts are found in it. All this matter has been washed out of the soil by the rivers which flow into the sea. It remains in the sea, since the water which evaporates from the surface is almost perfectly pure; but the surplus is continually taken up by marine plants and animals, so that the sea becomes no salter.

25. *Water in Plants and Animals.*—Water constitutes the greater part of all plants and animals. The human body is four-fifths water. In many of the lower animals the proportion is much greater. From a sun-fish weighing 30 pounds, only 240 grains of solid matter were obtained; so that water makes up about .999 of the weight of such animals. The vegetable substances which we use for food contain almost as large a percentage of water. In potatoes, the fraction is .75; in apples, .80; in turnips, .90; in watermelons, .94; and in cucumbers, .97.

26. *Water of Crystallization.*—Many salts, in crystallizing from their solutions, unite with a definite quantity of water, which is then called *water of crystallization*. If the salt be heated, the water is driven off, and the crystals fall to pieces; but the chemical properties of the substance are not altered. Many salts part with this water by mere exposure to the air, and *effloresce*; that is, crumble into white powder. Sodid carbonate (carbonate of soda) is an efflorescent salt. Other salts, on the contrary, like potassic carbonate (carbonate of potash), absorb water from the air, and become moist, or even dissolve; in which case they are said to *deliquesce*.

27. *Uses of Water.*—“On the uses of water it is almost needless to enlarge, for they are universally felt and appreciated. In each of its three physical conditions, the blessings which it confers on man are inestimable. As ice, it furnishes in northern lands, for months together, a solid bridge of communication between distant places: in the liquid condition, it is absolutely necessary to the existence of vegetable and animal life; in this shape, too, it furnishes to man a continual source of power in the flow of streams and rivers; it supplies one of the most convenient channels of communication between places widely separated; and further, it is the storehouse of countless myriads of creatures fitted for use as food: in the state of vapor, as applied in the steam-engine, it has furnished a power which has, in late years, done more than any other physical agent to advance civilization, to economize time, and to ameliorate the social condition of men. In each and all of these points, if rightly considered, we must perceive the entire adaptation of this compound to the ends which it was designed by the Creator to fill.

“Glancing at the physical condition of our planet, we cannot fail to be impressed with the important effects produced by the movements of water at periods anterior to the existence of man, as well as in more recent times. To such causes must we refer the formation of sedimentary rocks, and their arrangement in successive strata upon the surface of the earth: even now, observation shows that denudation is proceeding at some points, elevation and filling-up at others; whilst the accumulation of drift, and a variety of other extensive geological changes, must be traced to the same ever-acting and widely-operating agency.

“It may further be observed, that there is no form of matter which contributes so largely as water to the beauty

and variety of the globe which we inhabit. In its solid state, we are familiar with it, in the form of blocks of ice, of sleet and hail, of hoar-frost fringing every shrub and blade of grass, or of snow protecting the tender plant, as with a fleecy mantle, from the piercing frosts of winter. The rare but splendid spectacles of mock suns, or *parhelia*, are due to the refractive power of floating spiculæ of ice upon the sun's rays. In its liquid condition, as rain or dew, it bathes the soil; and the personal experience of all will testify to the charm which the waterfall, the rivulet, the stream, or the lake, adds to the beauty of the landscape; whilst few can behold unmoved the unbounded expanse of ocean, which, whether motionless, or heaving with the gently undulating tide, or when lashed into fury by the storm which sweeps over its surface, seems to remind man of his own insignificance, and of the power of Him who alone can lift up or quell its roaring waves. In vapor, how much variety is added to the view by the mist or the cloud, which, by their ever-changing shadows, diversify, at every movement, the landscape over which they are flitting; whilst the gorgeous hues of the clouds around the setting sun, and the glowing tints of the rainbow, are due to the refractive action of water and watery vapor upon the solar rays." \*

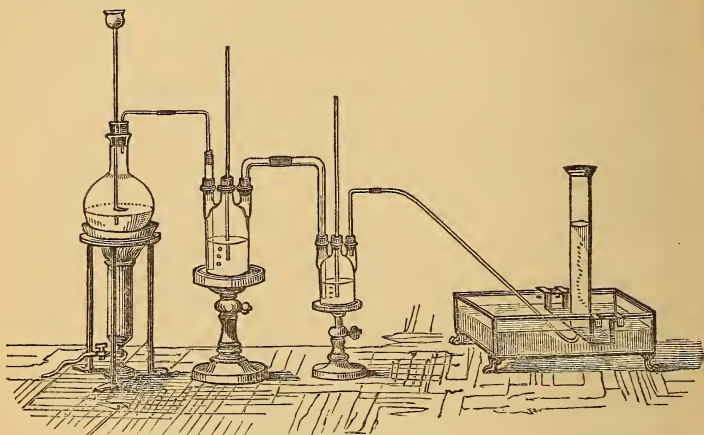
## NITROGEN.

28. *Preparation of Nitrogen.*—Pure nitrogen may be readily prepared by passing a stream of chlorine gas through strong aqua ammonia. It is well to pass the nitrogen through a *wash-bottle*, to remove the white fumes, which, as we have seen (3), are a compound of hydrogen and nitrogen. The apparatus used is shown in

\* Miller's Elements of Chemistry, Part II. pp. 35, 36.

Figure 10. The chlorine is generated in the flask at the left; the ammonia is put in the next bottle; and the nitro-

Fig. 10.

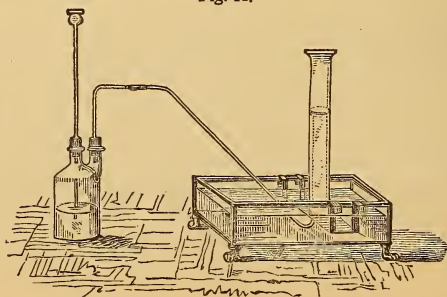


gen is washed in the third bottle, by being made to bubble up through water.

29. *Properties of Nitrogen.*—Nitrogen is a colorless gas, and is a little lighter than air. Its chief characteristic is its *inertness*. We have already seen (3) that it neither burns nor allows a taper to burn in it.

30. *Nitric Oxide.*—Put some bits of copper into a bottle (Figure 11), and add *aqua fortis* or *nitric acid*. A

Fig. 11.





reddish gas fills the upper part of the bottle, and passes off through the tube. When collected over water, it is colorless. The red color was owing to impurities, which have been absorbed by the water.

Invert a jar of this gas over a piece of well-lighted phosphorus, and the latter burns almost as brilliantly as in oxygen, filling the jar with white fumes of *phosphoric anhydride* (*phosphoric acid*.) The experiment proves the presence of oxygen in the gas in which the phosphorus was burned.

Pass a mixture of equal parts of this same gas and hydrogen through a tube containing some heated *platinized asbestos*, and hold a piece of moistened red litmus-paper at the mouth of the tube. The paper is turned blue, showing that *ammonia* has been produced; for ammonia is the only gas that turns red litmus-paper blue. We have seen (3) that ammonia is a compound of hydrogen and nitrogen; therefore there must have been nitrogen in the gas mixed with the hydrogen.

The gas is, in fact, a compound of nitrogen and oxygen, and is called *nitric oxide* (*deutoxide* or *binoxide of nitrogen*), and its symbol is NO.

31. *Catalysis*.—In the above experiment the platinized asbestos remains wholly unchanged. By its mere *presence*, it has made the hydrogen unite with the elements of the gas mixed with it. This remarkable action by mere presence is called *catalysis*. It occurs in many other cases, but is very imperfectly understood.

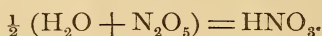
32. *Nascent State*.—Nitrogen, as we have seen, is a very *inert* substance. Indeed, it can be made to combine *directly* with scarcely any element. In the above experiment, the hydrogen first seizes upon the oxygen, forming water, and sets the nitrogen free. At the moment when it is thus set free it has an increased activity, and readily unites with the hydrogen to form ammonia.

It is found generally true that elements are unusually active when just liberated from compounds. They are then said to be in the *nascent state*.

33. *Nitrous Anhydride*.—If a jar of oxygen be inverted over a jar of *nitric oxide*, the gases, on mixing, become of a bright cherry-red color. The compound formed differs from nitric oxide only in containing more oxygen. It is called *nitrous anhydride (nitrous acid)*, and its formula is  $N_2O_3$ .

34. *Nitric Peroxide and Nitric Anhydride*.—It is possible to form two higher oxides of nitrogen,  $NO_2$ , *nitric peroxide*, and  $N_2O_5$ , *nitric anhydride*.

The former, at a temperature below  $70^\circ$ , is an orange-colored liquid; and the latter is a white solid, which eagerly unites with water, forming the well-known *aqua-fortis*, or *nitric acid*,  $HNO_3$ . The reaction between *nitric anhydride* and water is shown by the following equation:—



35. *Nitric Acid*.—Nitric acid is a strongly fuming liquid, colorless when pure, but usually yellowish from the presence of some of the lower oxides of nitrogen. It is one of the most corrosive substances known, and rapidly destroys all animal substances. When diluted, it stains the skin, wool, feathers, and the like, a bright yellow color, and is often used as a permanent yellow dye for silk and woollen goods. It acts violently upon tin and iron filings, especially when they are moistened with water. Indeed it attacks all the ordinary metals, except gold and platinum. Its action upon them, however, is more energetic when it is somewhat dilute.

The action of nitric acid upon the metals is owing to the readiness with which it parts with some of its oxygen. It first oxidizes them, and then acts upon these



basic oxides (16), to form salts (17). During this process, the lower oxides of nitrogen are always given off, as is indicated by the appearance of red fumes.

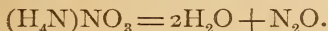
Nitric acid may be made on a small scale by heating potassic nitrate (saltpetre), in a retort with sulphuric acid (oil of vitriol). The nitric acid distils over, and is collected in a receiver. The re-action is as follows:—



The hydrogen and the potassium change places, giving rise to potassic sulphate (sulphate of potash) and nitric acid.

On the large scale, iron retorts, coated with fire-clay on the inside of the upper part, where they are exposed to the acid vapors, are employed for the distillation, and sodic nitrate (soda saltpetre) is substituted for potassic nitrate, as it is a cheaper salt, and likewise yields 9 per cent more nitric acid than potassic nitrate.

36. *Nitrous Oxide*.—A fifth oxide of nitrogen is obtained by gently heating ammonic nitrate (nitrate of ammonia). It is called *nitrous oxide*, and its symbol is  $\text{N}_2\text{O}$ . The reaction is shown by the following equation:—



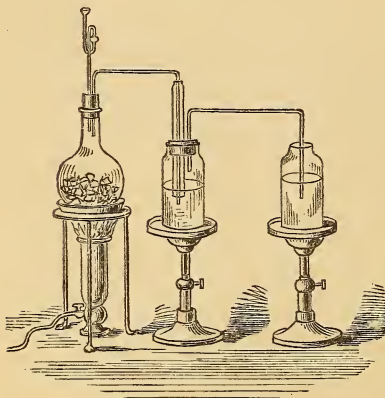
The ammonic nitrate,  $(\text{H}_4\text{N})\text{NO}_3$ , breaks up into water and nitrous oxide.

$\text{N}_2\text{O}$  is a colorless gas, and readily gives up its oxygen. Phosphorus burns in it as brilliantly as in pure oxygen. A splint of wood with a spark on the end of it bursts into flame when plunged into the gas. When inhaled, it has a peculiarly exhilarating effect, and hence is called *laughing gas*. It is used by dentists as an *anæsthetic*, since it makes the patient for the time insensible to pain. Great care must be taken that the gas when inhaled is *perfectly pure*.

37. *Ammonia*.—We have seen (3) that ammonia is a compound of hydrogen and nitrogen. It is a colorless gas, which is greedily absorbed by water, forming the ordinary *aqua ammonia*. The eagerness with which it is taken up by water may be shown by filling a jar with the gas and opening it under water. The gas is instantly absorbed, and the water rushes in and fills the bottle. At a temperature of  $32^{\circ}$ , water will absorb more than one thousand times its bulk of ammonia.

Ammonia takes its name from the fact that it was first obtained from a salt found in Libya, near the temple of

Fig. 12.



Jupiter Ammon. It is now prepared from the same salt, *sal-ammoniac* or *ammonic chloride*, which is made in large quantities from the waste liquor of gas-works. The sal-ammoniac is powdered and mixed with lime, and the mixture is heated in a flask arranged as shown in Figure 12.

The gas is washed by passing it through a wash-bottle, and is then conducted into water.

38. *Ammonium*.—The symbol of *ammonic chloride* is  $(\text{H}_4\text{N})\text{Cl}$ ; that of *ammonic nitrate* is  $(\text{H}_4\text{N})\text{NO}_3$ . If we compare these with the symbols of the potassic chloride and nitrate,  $\text{KCl}$  and  $\text{KNO}_3$ , we shall see that the group of atoms  $\text{H}_4\text{N}$  plays the same part in the compounds as the *metal* potassium; and this is the case in a large class of salts. Hence this group of atoms has come to be considered as a *metal*, and has received the

name of *ammonium*. It has not, however, been obtained in a separate form, since it at once breaks up into ammonia,  $\text{H}_3\text{N}$ , and hydrogen.

39. *Cyanogen*. — When carbon and nitrogen are heated together in the presence of potash, a remarkable compound called *potassic cyanide* (*cyanide of potassium*),  $\text{KCN}$ , is formed. From this a large number of substances can be prepared, all of which contain the group of atoms  $\text{CN}$ . To this group the name *cyanogen* (blue-maker) is given, from its forming a number of blue compounds. It is remarkable as entering into composition exactly like a non-metallic element. It can be obtained in a free state as a colorless gas by heating mercuric cyanide (cyanide of mercury.) It forms with hydrogen an acid,  $\text{HCN}$ , analogous to muriatic acid,  $\text{HCl}$ . This acid is called *hydrocyanic* or *prussic acid*.

The most important of the blue compounds of cyanogen is *Prussian blue*, which may be formed by mixing a solution of either the *red* or the *yellow prussiate of potash* with a solution of *green vitriol*.

Groups of atoms, like  $\text{H}_2\text{N}$  and  $\text{CN}$ , which play the part of elements, are called *radicals*.

40. *The Characteristics of Nitrogen*. — The most marked features of nitrogen are its *inertness* (29); the *indirect way in which it enters into combination*; and the *great variety, the remarkable nature, and the instability of its compounds*.

The *great variety* of its compounds is shown in the five which it forms with oxygen: —

Nitrous oxide,	$\text{N}_2\text{O}$ .
Nitric oxide,	$\text{NO}$ .
Nitrous anhydride,	$\text{N}_2\text{O}_3$ .
Nitric peroxide,	$\text{NO}_2$ .
Nitric anhydride,	$\text{N}_2\text{O}_5$ .

These compounds, as we have seen, are widely unlike in their properties ; but in *composition* they differ only in the amount of oxygen which they contain.

The *remarkable nature* of the compounds is illustrated by *ammonium* and *cyanogen*, one of which acts like a *metallic* and the other as a *non-metallic element*.

The *instability* of the compounds is seen in the readiness with which the oxides give up their oxygen. *Nitric iodide* (*iodide of nitrogen*), which may be prepared by the action of ammonia on iodine, is so unstable that it explodes even when touched with a feather. *Nitric chloride* (*chloride of nitrogen*) is even more explosive, and is one of the most dangerous compounds known.

## CARBON.

41. *Properties of Carbon*.—Carbon differs from the elements already described in being a solid when in a free state. It exists in three forms, which in outward appearance have nothing in common, but which are identical in their chemical relations. These three *allotropic* forms are *diamond*, *graphite* or *plumbago*, and *charcoal*. These differ in hardness, color, specific gravity, and the like ; but when burnt in oxygen, the same weight of each produces the same weight of carbonic acid.

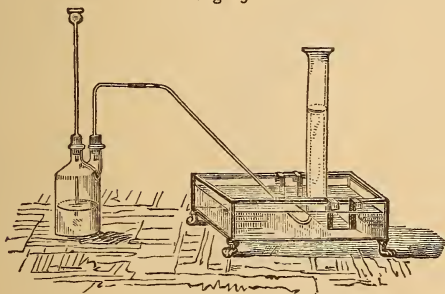
The *diamond* was first found to be pure carbon by Lavoisier in 1775-76. It occurs crystallized in certain rocks and gravels in India, Borneo; and Brazil. It is the hardest of all known bodies ; and when cut, has a brilliant lustre and a high refractive power.

*Graphite*, *plumbago*, or *black lead*, is the substance used in the manufacture of the so-called "lead pencils." Although very brittle, its particles are very hard, so that a saw or other instrument used in cutting it is soon dulled. Mixed with oil it is extensively used to diminish

the friction of machinery. It is the basis of most kinds of *stove-polish*, and of certain paints used to protect iron-work. It is also made into crucibles, which, on account of their infusibility, are much prized by the chemist. Carbon, in all its forms, is the most infusible substance known. Its *infusibility* and its *allotropic states* are its chief characteristics.

42. *Carbonic Anhydride (Carbonic Acid)*.—The most important compound of carbon is  $\text{CO}_2$ , *carbonic anhydride*, commonly called *carbonic acid*. This gas is readily prepared by the action of dilute muriatic acid on

Fig. 13.



chalk or marble (Figure 13). The reaction is as follows:—



$\text{CaCO}_3$ , *calcic carbonate* (chalk, or marble), is broken up by the action of the acid. The calcium combines with the chlorine of the acid, forming *calcic chloride* (*chloride of calcium*),  $\text{CaCl}_2$ ; one atom of the oxygen combines with the hydrogen of the acid, forming *water*; and  $\text{CO}_2$  is set free.

We have already seen (11) that lime-water readily shows the presence of carbonic acid, by becoming milky white. The lime-water contains lime,  $\text{CaO}$ , which com-

bins with the carbonic acid,  $\text{CO}_2$ , to form  $\text{CaCO}_3$  again.

If a lighted taper be plunged into a jar of carbonic acid, it goes out. We have seen that the same thing takes place in nitrogen; but the two gases can be distinguished by the lime-water test.

Carbonic acid is about 1.5 times as heavy as air, so that, with an ordinary dipper, it can be dipped out from one jar and poured into another, like water. It is poisonous when breathed, even though mixed with a large quantity of air.

43. *Carbonic Oxide*.—Carbonic oxide,  $\text{CO}$ , is a gas formed when carbon burns with a limited supply of oxygen. It is often produced in an ordinary coal-fire, and is seen to burn with a pale blue flame. It is far more poisonous than carbonic acid.

$\text{CO}$  may be obtained pure from several compounds of carbon. Thus, if crystallized oxalic acid,  $\text{C}_2\text{H}_2\text{O}_4$ , be heated with strong sulphuric acid, the latter withdraws from it one molecule of water,  $\text{H}_2\text{O}$ , leaving  $\text{C}_2\text{O}_3$ , which at once splits up into  $\text{CO}$  and  $\text{CO}_2$ . The  $\text{CO}_2$  may be removed by passing the mixed gases through a solution of caustic soda.

## SULPHUR.

44. *Sources of Sulphur*.—Sulphur occurs in nature both free and combined: it is found free in certain volcanic countries, especially in Sicily and Iceland; it exists in combination with many metals, forming *sulphides*. These sulphides are the ores from which several of the metals are commonly obtained. Thus  $\text{PbS}$ , plumbic sulphide (galena),  $\text{ZnS}$ , zincic sulphide (zinc blende), and  $\text{CuS}$ , cupric sulphide (sulphide of copper), are the most productive ores of those metals.

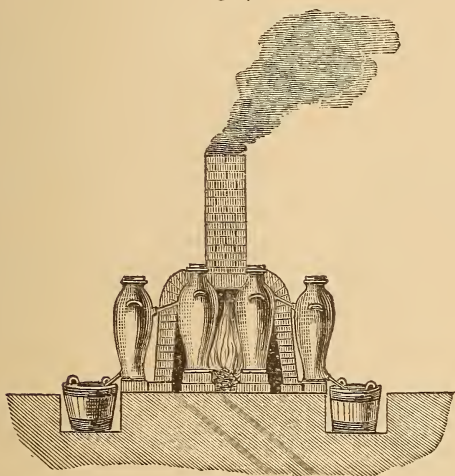
In order to obtain pure sulphur, the mineral, containing



the crude substance mixed with earthy impurities, is heated in earthen pots (Figure 14); the sulphur distils over in the form of vapor, which is condensed in similar pots placed outside the furnace. The sulphur thus obtained is refined or purified by a second distillation.

If the vapor of sulphur is quickly cooled below its melting-point, it solidifies in a crystalline powder, called *flowers of sulphur*; just as watery vapor, when cooled below the freezing point of water, becomes snow. If

Fig 14.



sulphur is gently heated, it melts, and may be cast into sticks, and is then known as *brimstone*, or *roll sulphur*.

45. *Properties of Sulphur*.—Sulphur is a yellow solid, and exists in three allotropic forms ( $1\frac{1}{2}$ ). The first is that in which it crystallizes in nature. The other two are obtained by melting sulphur. If melted sulphur be allowed to cool slowly, it crystallizes in long, transparent needle-shaped crystals, which are quite different in form from the natural crystals, and have a specific

gravity of 1.98, while the natural crystals have a specific gravity of 2.07. These transparent crystals become opaque after an exposure of a few days to the air, owing to their breaking up into several crystals of the natural and permanent form. The third allotropic form of sulphur is obtained by pouring melted sulphur at  $450^{\circ}$  into cold water. It then forms a soft, tenacious mass, resembling india-rubber, and has a specific gravity of 1.96. This form of sulphur is not permanent. In a few hours it returns to its ordinary brittle state. These peculiar modifications are also apparent when sulphur is heated. It begins to melt at  $239^{\circ}$ , and forms an amber-colored limpid liquid; as the temperature rises, it begins to thicken, and to become dark-colored, so that at about  $450^{\circ}$  it can scarcely be poured from the vessel; heated still higher, it again becomes fluid, and remains as a dark thin liquid, till the temperature rises to  $836^{\circ}$ , when it begins to boil, and gives off a red vapor.

Sulphur is an inflammable substance, and when heated in the air or oxygen burns with a bluish flame, and with the suffocating odor so well known in the burning of a common lucifer match. It is insoluble in water and in most liquids, but dissolves in carbonic disulphide (50).

46. *Sulphurous Anhydride (Sulphurous Acid)*.—This compound,  $\text{SO}_2$ , as we have seen (11), is formed when sulphur is burned in oxygen, or in the air, which is a mixture of oxygen and other gases. The suffocating odor which we perceive when a common friction match is lighted is caused by  $\text{SO}_2$ .

The most important property of  $\text{SO}_2$  is its power of bleaching silk, woollen, straw, etc. It is largely used for this purpose in the arts.

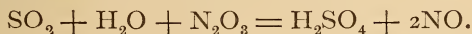
This property may be illustrated by holding a red rose or other flower in a jar of  $\text{SO}_2$ . The flower quickly loses its color.



47. *Sulphuric Acid*.—Sulphuric acid, or *oil of vitriol*, is the most important and most powerful of all the acids. It has a very strong attraction for water, and when the two are mixed, intense heat is developed. Hence caution is necessary in mixing them, especially in thick glass vessels. The acid should always be poured into the water, not the water into the acid. It rapidly chars all organic matter, and is a valuable drying agent.

Sulphuric acid was first prepared by distilling *green vitriol*, or *ferrous sulphate*, whence its name, *oil of vitriol*. In this form it is sometimes known as *Nordhausen acid*, from the name of the city in Saxony where it was first manufactured. It is a fuming liquid, denser than the ordinary acid, and is a mixture of this acid with the *sulphuric anhydride*.

This method has long been superseded by a more convenient one, which depends upon the fact that, though  $\text{SO}_2$  does not combine with free oxygen and water to form sulphuric acid, it is capable of taking up the oxygen when the latter is united with nitrogen in the form of *nitrous anhydride*,  $\text{N}_2\text{O}_3$ . Thus:—



Sulphurous anhydride, water, and nitrous anhydride, yield sulphuric acid and nitric oxide.

The NO formed in this decomposition takes up another atom of oxygen from the air, becoming  $\text{N}_2\text{O}_3$ , and this is again able to convert a second molecule of  $\text{SO}_2$ , with water,  $\text{H}_2\text{O}$ , into sulphuric acid,  $\text{H}_2\text{SO}_4$ ; being a second time reduced to NO, and ready again to take up another atom of oxygen from the air. Hence it is clear that the NO acts simply as a carrier of oxygen between the air and the  $\text{SO}_2$ ; and a very small quantity of it is therefore able to convert a very large quantity of sulphurous anhydride, water, and nitrous anhydride, into sulphuric acid.

This process is conducted on a large scale in chambers made of sheet-lead, which are often of a capacity of 50,000 or 100,000 cubic feet. The sulphurous anhydride is obtained either by burning sulphur in a current of air, or by roasting a mineral called *iron pyrites* (ferric bisulphide,  $\text{FeS}_2$ ), and is led, together with air, into the chamber. The  $\text{N}_2\text{O}_3$  is got from sodic nitrate (soda salt-petre), which is decomposed either by the heat of the burning sulphur, or in a separate furnace. Jets of steam are also blown into the chamber, and a thorough draft is maintained by a high chimney. The sulphuric acid, as it forms, falls to the floor of the chamber, whence it is continually drawn off. It is then heated, first in open leaden pans, and then in vessels of glass or platinum (as lead is attacked by the strong acid), until the excess of water is driven off, and a sufficiently concentrated acid is obtained.

So extensively is this acid used, that the quantity manufactured in South Lancashire (England) alone exceeds 3,000 tons a week.

This method of making sulphuric acid may be illustrated, on a small scale, by dipping a shaving or cloth in nitric acid, and then holding it in a jar of sulphurous anhydride, with a little water at the bottom of the jar. Red fumes at once appear, which show that the nitric acid has lost some of its oxygen, having given it up to the  $\text{SO}_2$ , which thus becomes  $\text{SO}_3$ . If the experiment be repeated a number of times, the water at the bottom of the jar will be found to contain sulphuric acid.

48. *Sulphuric Anhydride*.—If fuming Nordhausen acid be gently heated in a glass retort, which is connected with a receiver, kept cool by ice, white fumes will pass over and solidify into a white silky fibrous mass. This solid is *sulphuric anhydride*. It has no acid properties, and can be moulded in the fingers with-

out charring the skin. When thrown on water, the heat emitted is so intense that it hisses like red-hot iron.

49. *Hydric Sulphide, Sulphuretted Hydrogen, or Hydrosulphuric Acid.*—Sulphur combines with hydrogen, forming *hydric sulphide*,  $\text{H}_2\text{S}$ , a compound analogous in composition to water. It is a gas of a very offensive odor, and very poisonous. It reddens litmus-paper, and is therefore an acid. It is best prepared by the action of dilute sulphuric acid on ferrous sulphide,  $\text{FeS}$ . Thus:—



The hydrogen and the iron change places, forming hydric sulphide and ferrous sulphate (sulphate of iron, or green vitriol).

This gas is an invaluable agent in chemical analysis.

50. *Carbonic Disulphide.*—If the vapor of sulphur be passed over red-hot charcoal, a volatile compound,  $\text{CS}_2$ , is formed. It is seen to be analogous to carbonic acid,  $\text{CO}_2$ . It is a very inflammable, colorless liquid, of an offensive odor, and is called *carbonic disulphide* (or *visulphide of carbon*). It is of great importance in the arts, since it dissolves gums, caoutchouc, sulphur, and phosphorus.

51. *The Oxygen Group.*—The two compounds,  $\text{H}_2\text{S}$  and  $\text{CS}_2$ , are analogous in composition to  $\text{H}_2\text{O}$  and  $\text{CO}_2$ , and it is true in general that for every *oxide* there is a corresponding *sulphide*. Thus we have  $\text{K}_2\text{O}$ , *potassic oxide* (*potassa*), and  $\text{K}_2\text{S}$ , *potassic sulphide* (*sulphide of potassium*);  $\text{BaO}$ , *baric oxide* (*baryta*), and  $\text{BaS}$ , *baric sulphide* (*sulphide of barium*);  $\text{Al}_2\text{O}_3$ , *aluminic oxide* (*alumina*), and  $\text{Al}_2\text{S}_3$ , *aluminic sulphide* (*sulphide of aluminium*); and so on.

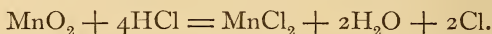
Oxygen and sulphur, then, belong to the same group of elements, which may be called the *oxygen group*. To

this group also belong the rare elements, *selenium* and *tellurium*.

It will be noticed that the atomic weight of sulphur, 32, is just double that of oxygen.

## CHLORINE.

52. *Preparation of Chlorine*.—Chlorine, as we have already seen (1), is prepared by heating a mixture of muriatic acid and black oxide of manganese,  $\text{MnO}_2$ . The reaction is shown in the following equation:—



The hydrogen of the  $\text{HCl}$  combines with the oxygen of the  $\text{MnO}_2$ , forming two molecules of water,  $2\text{H}_2\text{O}$ . Half the chlorine of the  $\text{HCl}$  unites with the manganese, to form *manganic chloride* (*chloride of manganese*),  $\text{MnCl}_2$ , and the other half is set free.

53. *Properties of Chlorine*.—Chlorine was discovered by Scheele in 1774. It does not occur free in nature, but is found combined with metals, forming *chlorides*, of which rock-salt is the most common. Chlorine is, as we have seen, a greenish-yellow gas of a most disagreeable and irritating odor. It is very poisonous when inhaled in any considerable quantity. It is a very heavy gas, being nearly 2.5 times as heavy as air. Chlorine has a very strong affinity for the metals. If these in a finely divided state are brought into contact with it, they take fire spontaneously, giving rise to metallic chlorides. It has so strong an affinity for phosphorus, that this element will take fire spontaneously when put into a jar of chlorine. But the most remarkable property of chlorine is its power of combining with hydrogen to form muriatic acid. When these gases are mixed in equal volumes, they combine with an explosion

on applying a lighted taper to them, or on exposing them to the sunlight. This property of chlorine has already been illustrated in the decomposition of water and ammonia (2, 3).

Another remarkable property of chlorine is its *bleaching* power, which depends on its ability to decompose water. We may enclose a piece of cotton cloth colored with a vegetable substance in a bottle of dry chlorine, and no change of color takes place, even after many weeks. If, however, a few drops of water are added, the cotton is at once bleached. The chlorine combines with the hydrogen of the water, and the oxygen, at the moment of its liberation, when it is in the *nascent state* (32), combines with the coloring matters, forming colorless compounds. Ordinary free oxygen has not this power, at least to any great extent.

54. *Chloride of Lime, or Bleaching Powder.*—Since chlorine destroys all organic colors (that is, all colors derived from the vegetable and animal kingdoms) it is very extensively used in bleaching cotton and linen goods and paper. Cotton fabrics may now be rendered perfectly white in a few hours; while, by the old method of laying them on the grass in the sun, it required weeks, and even months, to effect it. It was necessary, moreover, to have meadow-land suitably situated for the bleaching; hence most of the cloth manufactured in England was carried to Holland to be bleached. Besides the diminished expense, the cotton stuffs bleached with chlorine suffer less injury in the hands of skilful workmen than those bleached in the sun.

The health of the workmen is greatly endangered by the use of chlorine in the gaseous state; but it has been found that the gas is readily absorbed by slaked lime, and is as readily given up again when the lime is treated with dilute acid.

When thus combined with lime, the chlorine can be easily transported. The compound is called *chloride of lime*, or *bleaching powder*.

This powder is made on a large scale by conducting chlorine into spacious chambers, on the floor of which slaked lime is spread to the depth of two inches.

In bleaching, the goods are first dipped into a solution of the bleaching powder, and then passed through dilute acid. The chlorine is thus set free in the fibres of the cloth, where it does its work of bleaching without injury to the workmen.

Chloride of lime is also largely used as a *disinfectant*. The chlorine acts upon organic *odors* in the same way as upon organic colors; that is, it *oxidizes* and destroys them.

55. *Hydric Chloride (Hydrochloric Acid)*.—*Hydric chloride* or *hydrochloric acid* is a colorless gas, somewhat heavier than air, and is very soluble in water. This solution is the ordinary *muriatic acid* of the shops. It may be easily prepared, by placing in a capacious retort 3 parts of fused sodic chloride (chloride of sodium, or common salt) in fragments, and adding slowly, through a bent funnel, 3 parts of oil of vitriol. If pounded salt be used, the action of the acid is apt to be too rapid. The retort is connected with a series of bottles; in the first, a small quantity of water is placed, to detain any impurities which might be carried over mechanically with the gas; the second bottle may contain 4 parts of water, and should be immersed in a vessel of cold water, as the condensation of the gas is attended with a great disengagement of heat. On applying a gentle heat to the retort, the acid comes over and is condensed; an easily soluble sodic sulphate (sulphate of soda) remains in the retort. For manufacturing purposes, the decomposition is effected in iron cylinders, like those employed in the manufacture



of nitric acid, and only one half the quantity of sulphuric acid prescribed above is used:—



Sodic sulphate,  $\text{Na}_2\text{SO}_4$ , remains in the cylinder, whilst the acid is condensed in a series of salt-glazed stone-ware jars.

Enormous quantities of muriatic acid are obtained as an incidental product in the manufacture of soda-ash, which will be described farther on. More than 1000 tons are made every week at the soda-ash works in South Lancashire (England) alone.

56. *Hydracids*.—Hydric chloride,  $\text{HCl}$ , and hydric sulphide,  $\text{H}_2\text{S}$ , contain each but two elements, and no oxygen; while nitric acid,  $\text{HNO}_3$ , and sulphuric acid,  $\text{H}_2\text{SO}_4$ , contain each three elements, one of which is oxygen. There are, then, two classes of acids: one containing oxygen, and called *oxyacids*; and the other, containing no oxygen, called *hydracids*.

57. *Aqua Regia*.—When muriatic acid is mixed with nitric acid, it forms the so-called *nitro-muriatic acid*. This acid was called *aqua regia* (royal water) by the alchemists, because it dissolves gold, the “king of metals.” Both platinum and gold are insoluble in either acid separately; but when the two acids are mixed, they decompose each other. Chlorine is set free, and in its nascent state (32) acts upon the metals, and dissolves them.

58. *Chlorine Oxyacids*.—Chlorine has a very weak affinity for oxygen; but it forms four oxyacids: *hypochlorous acid*,  $\text{HClO}$ ; *chlorous acid*,  $\text{HClO}_2$ ; *chloric acid*,  $\text{HClO}_3$ ; and *hyperchloric* or *perchloric acid*,  $\text{HClO}_5$ . Of these, the hypochlorous and the chloric form some important salts.

## BROMINE.

59. *Properties of Bromine.*—This element, which closely resembles chlorine in its properties and compounds, was discovered by Balard, in 1826, in the salts obtained by the evaporation of sea-water. It does not occur free in nature, and is, like chlorine, found combined with sodium and magnesium as *bromides* in certain mineral springs.

Bromine is a dark, reddish-black, heavy liquid, being the only element, except mercury, that exists as a liquid at the ordinary temperature. Its specific gravity is 2.966, it freezes at  $-9^{\circ}$ , and boils at  $145^{\circ}$ . It has a very strong, irritating smell, resembling that of chlorine, and when inhaled, acts as a violent poison. It is quite soluble in water, and this solution bleaches, but more feebly than a solution of chlorine. Some of its salts are much used in medicine and in photography.

## IODINE.

60. *Properties of Iodine.*—Iodine also occurs in sea-water, combined with sodium and magnesium. It was discovered in 1812 by Courtois. At the ordinary temperature it is a dark gray solid, with a bright metallic lustre. It has a specific gravity of 4.95; it melts at  $225^{\circ}$ , and boils at about  $350^{\circ}$ . Its vapor is of a beautiful deep violet color, and has a faint chlorine-like smell. Iodine does not possess such active qualities as either chlorine or bromine. Its solution does not bleach vegetable colors, and it is set free from its compounds by both the above elements. Free iodine forms with starch a remarkable compound of a rich blue color (12). Iodine acts as a violent poison; but, given in small quantities, it is much used as a medicine. Some of its salts also are used in medicine and in photography.



## FLUORINE.

61. *Properties of Fluorine.*—This element occurs combined with the metal calcium, as calcic fluoride (fluoride of calcium) or *fluor-spar*. It is remarkable as forming no compound with oxygen, and as being extremely difficult to prepare in a pure state. Many unsuccessful attempts have been made to obtain fluorine; but, by the action of dry iodine upon dry argentic fluoride (fluoride of silver), it appears to have been isolated; and it is found to be a colorless gas.

62. *Hydric Fluoride, or Hydrofluoric Acid.*—When calcic fluoride (fluor spar) is acted upon by sulphuric acid, a very corrosive gas is obtained, called *hydric fluoride* (*hydrofluoric acid*). The reaction is shown in the following equation:—



The calcium and the hydrogen change places, forming *calcic sulphate* (*sulphate of lime*),  $\text{CaSO}_4$ , and hydric fluoride.

This acid must be prepared in vessels of lead or platinum, since it rapidly attacks glass. It acts violently upon the skin, producing painful sores, and the fumes are very poisonous to the lungs. It is used for etching on glass. The glass is first covered with wax, through which the design is traced with a sharp point. The glass is then exposed to the gas, which corrodes it where the wax has been removed. The solution of the gas in water is also used for the same purpose.

63. *The Chlorine Group.*—The four elements just described form a well-marked group. They are especially remarkable for their gradation of properties. Thus chlorine is a gas, bromine a liquid, and iodine a solid, at the ordinary temperature. Chlorine may be easily con-

densed into a liquid, and the specific gravity of liquid chlorine is 1.33, of bromine 2.97, and of iodine 4.95. Liquid chlorine is transparent, bromine slightly so, and iodine opaque. The atomic weight and density of bromine are nearly the mean of those of chlorine and iodine,  $\frac{35.5 + 127}{2} = 81.25$ ; and in its general chemical deportment bromine stands half-way between the other two elements.

These elements all form powerful acids with hydrogen, and have a strong affinity for the metals. They all have a very weak affinity for oxygen.

## PHOSPHORUS.

64. *Properties of Phosphorus.*—This element does not occur free in nature, but is found combined with oxygen and calcium in large quantities in the bodies, especially the bones, of animals, and in the seeds of plants. Animals obtain their phosphorus from plants, plants from the soil, and the soil from the slow disintegration of the oldest rocks. Phosphorus was accidentally discovered by Brande, in 1669; but Scheele, in 1769, pointed out its existence in the bones, and carefully examined its properties. It is prepared from bones, and is used chiefly in the manufacture of lucifer matches.

Phosphorus is a yellowish, semi-transparent solid, resembling wax. Its specific gravity is 1.83. It melts at  $111^{\circ}$ , and boils at  $550^{\circ}$ . In the air it gives off white fumes, and emits a pale light in the dark, whence its name, which means *light-bearer*. While emitting this light, it appears to be undergoing a slow burning. At a temperature a little above its melting-point, phosphorus takes fire in the air, and burns with great energy. It

may be set on fire by slight friction, by a blow, and even by the heat of the hand. Hence it should be handled with great care, and always be cut under water. Phosphorus has several well-marked allotropic states, the most important of which is that known as *red phosphorus*. This is much less inflammable than ordinary phosphorus, and is not poisonous.

65. *Compounds of Phosphorus*.—Phosphorus combines with oxygen, to form several acids, the most important of which are known as *hypophosphorous acid* and *phosphoric acid*. From the former are derived salts (*hypophosphites*), used in medicine; while the latter furnishes a large class of salts (*phosphates* and *superphosphates*), which are valuable to the farmer as fertilizers. Phosphorus unites with hydrogen, to form *hydric phosphide* (phosphuretted hydrogen),  $\text{H}_3\text{P}$ , a poisonous gas, with a very offensive odor. When this gas is prepared by the action of caustic potash on phosphorus, each bubble of the gas takes fire as it comes into contact with the air, forming beautiful rings of phosphoric anhydride (phosphoric acid), which expand as they rise. This spontaneous combustion is owing to the presence of a small quantity of a liquid compound of phosphorus and hydrogen, whose symbol is  $\text{H}_2\text{P}$ . Pure phosphuretted hydrogen does not take fire in this way.

## ARSENIC.

66. *Properties of Arsenic*.—Arsenic closely resembles phosphorus and nitrogen in its chemical properties, and in those of its compounds, and is therefore to be counted as a non-metallic element. In physical features, such as specific gravity and lustre, it bears a greater resemblance to the metals, with which it was formerly classed. (See, in Appendix, *Chemical Philosophy*, § 19.)

Arsenic is sometimes found in a free state, but more often combined, chiefly with iron, nickel, cobalt, and sulphur. One of the compounds of this element with oxygen,  $\text{As}_2\text{O}_3$ , is the well-known poison, *white arsenic*.

67. *The Nitrogen Group*.—Nitrogen, phosphorus, and arsenic form a well-marked group. They all form similar compounds with oxygen and with hydrogen. Thus we have  $\text{H}_3\text{N}$  (ammonia),  $\text{H}_3\text{P}$  (phosphuretted hydrogen), and  $\text{H}_3\text{As}$  (hydric arsenide);  $\text{N}_2\text{O}_3$  (nitrous anhydride),  $\text{N}_2\text{O}_5$  (nitric anhydride),  $\text{P}_2\text{O}_3$  (phosphorous anhydride),  $\text{P}_2\text{O}_5$  (phosphoric anhydride), and  $\text{As}_2\text{O}_3$  (arsenious anhydride),  $\text{As}_2\text{O}_5$  (arsenic anhydride).

## BORON.

68. *Properties of Boron*.—Boron is found in nature combined with oxygen as *boracic acid*, and with oxygen and sodium as *borax*. In certain volcanic districts in Tuscany, jets of steam and gas are continually escaping from the earth. These steam-jets contain small quantities of boracic acid, which collects in artificial basins formed for the purpose at the mouth of the jet. By means of the heat of natural steam-jets, this solution of boracic acid is concentrated and crystallized. About 2,000 tons of crude acid are thus prepared and exported from Tuscany every year.

Boron is remarkable as combining directly with nitrogen at a high temperature.

## SILICON.

69. *Properties of Silicon*.—Next to oxygen, silicon is the most abundant element known. It does not, however, occur in a free state, but always combined with oxygen (for which it has a very strong affinity) as *silica*.

Silica is found nearly pure in quartz, flint, sand, and in several minerals, and combined with metals in almost all known rocks. Its symbol is  $\text{SiO}_2$ .

Silicon can be obtained in three modifications, corresponding to the three states of carbon.

70. *The Carbon Group*.—Carbon and silicon, then, form a well-marked group, resembling each other closely in their allotropic states.

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### SUMMARY.

Chemistry divides substances into two classes :—

1st, *Elements*, or substances which cannot be decomposed by any known process. Of these only 65 are known.

2d, *Compounds*, or substances made up of elements.

The *force* which causes elements to combine, and holds them in combination, is called *Affinity*.

*Affinity changes the properties of the substances which it combines.*

*Affinity always causes substances to combine in fixed and definite quantities.* This law of combination is called the *Law of Definite Proportions*.

*A given element combines with some elements in preference to others.*

Matter is made up of *molecules*; and molecules are made up of *atoms*.

The compounds of nitrogen and oxygen show that the same elements may combine in more than one proportion, and that in such cases the proportions of the elements in the compounds are always *multiples* of the *atomic weights* of the elements. This law of combination is known as the *Law of Multiple Proportions*.

The symbol of an *element* is usually the first letter of its name, a second letter being added to distinguish

names beginning with the same letter. The symbol of an element always stands for *one atom* of the element.

The symbol of a *compound* indicates its composition. It is formed by writing together the symbols of the elements of the compound, with a small figure after each symbol expressing the number of atoms of that element found in a molecule of the compound. The symbol of a compound always stands for *one molecule* of the compound.

The chemical changes, or *reactions*, which substances undergo, are indicated by *equations* made up of these symbols.

The compounds of oxygen with the elements are called *oxides*. These oxides are either *acid*, *neutral*, or *basic*. The oxides of the non-metallic elements are generally acid; those of the metallic elements are generally basic.

The acid oxides combined with water form *acids*.

The basic oxides combined with water form *bases*.

When a metal takes the place of the hydrogen of the acid, the compound is called a *salt*.

A *hydracid* is made up of hydrogen and a non-metallic element.

The names of *binary salts* take the ending *-ide*; those of *ternary salts*, the endings *-ate* or *-ite*, according as the name of the acid ends in *-ic* or *-ous*.

In general, the name of a binary compound takes the ending *-ide*.

*Oxygen* is the most abundant element, and is usually prepared from potassic chlorate. It has a wider range of affinities than any other element.

*Ozone* is an allotropic form of oxygen, and is more active than ordinary oxygen.

*Hydrogen* is the lightest element, and is usually obtained by the action of zinc on dilute sulphuric acid. Its most important compound is *water*.



*Nitrogen* is one of the most inert of elements. It is remarkable for the indirect way in which it enters into combination, and for the variety and the nature of its compounds.

*Carbon* is an infusible solid, and has three allotropic states.

*Sulphur* is an inflammable solid, forming *sulphides* which in their composition resemble oxides. It has several remarkable allotropic states.

*Chlorine* is most readily prepared by the action of black oxide of manganese on muriatic acid. It is distinguished by its color, its odor, and its affinity for hydrogen and the metals. Its bleaching and disinfecting power is due to its strong affinity for hydrogen.

*Bromine*, *iodine*, and *fluorine* are elements closely resembling chlorine in their chemical properties.

*Phosphorus* is a very inflammable substance, and is mainly used for making lucifer matches. It is obtained from bones.

*Phosphorus* and *arsenic* resemble nitrogen in the compounds which they form.

*Silicon* resembles carbon in its allotropic states.

*Boron* combines directly with nitrogen at a high temperature.

*Nitric acid* is remarkable for its *oxidizing* power.

*Sulphuric acid* is the strongest of acids, and is remarkable for its affinity for water.

*Sulphurous acid* is a bleaching agent.

*Nitrous oxide* is used as an anæsthetic.

*Carbonic acid* is a heavy gas, and is most readily prepared by the action of muriatic acid on marble.

The most important non-metallic *sulphides* are *hydric sulphide* and *carbonic bisulphide*.

The most important of the non-metallic *chlorides* is *muriatic acid*.

*Cyanogen* is a remarkable compound of nitrogen and carbon, and plays the part of a non-metallic element.

*Ammonium* is a remarkable compound of nitrogen and hydrogen, and plays the part of a metal.

*Ammonia*, although it is not an oxide, has very powerful basic properties. It is known as the *volatile alkali*, and is extensively used in the arts.



# THE METALS.



## GENERAL PROPERTIES OF THE METALS.

71. *Physical Properties of the Metals.* — The metals differ widely from one another, both in their physical and chemical properties. Those metals which are lightest have the greatest affinity for oxygen, whilst the heavier metals are oxidized with difficulty.

The following Table gives the specific gravities of the most important metals:—

Iridium	21.8	Iron	7.8
Platinum	21.5	Tin	7.3
Gold	19.3	Zinc	7.1
Mercury	13.596	Antimony *	6.7
Lead	11.3	Chromium	5.9
Silver	10.5	Aluminium	2.56
Bismuth *	9.8	Strontium	2.54
Copper	8.9	Magnesium	1.75
Nickel	8.8	Calcium	1.58
Cadmium	8.6	Sodium	0.972
Cobalt	8.5	Potassium	0.865
Manganese	8.0	Lithium	0.593

The melting-points of the metals differ even more widely than their densities, as will appear from the following Table, which is mainly compiled from Miller:—

\* In their *chemical* properties, bismuth and antimony appear to be non-metals. See § 99, p. 73.

Mercury	—39°	Antimony	+737°
Cadmium	+242	Silver	1873
Tin	442	Copper	1996
Bismuth	507	Gold	2016
Lead	617	Steel	2350 to 2500
Zinc	733	Wrought Iron	2700 to 2850

Some metals can be easily converted into vapor, or volatilized; thus mercury boils at 662°, while potassium, sodium, magnesium, zinc, and cadmium can be distilled at a red heat. Even the more infusible metals, such as copper and gold, are not absolutely fixed, but give off small quantities of vapor when strongly heated.

72. *Metallic Ores.*—Only a few of the metals occur in a free state in nature; in general they are found combined with oxygen, sulphur, or some other non-metal. These metallic compounds are most variously distributed throughout the earth's crust; some are known to occur in only one or two localities, and even then only in minute quantity, while others are found widely distributed in enormous masses. Aluminium, iron, calcium, magnesium, and sodium form, when united with oxygen and silicon, the whole mass of granitic rocks composing our globe; but it is not from these sources that they can be obtained for the purposes of the arts. For this object we employ other combinations, found in smaller quantity, termed *metallic ores*, from which the metals can be more easily extracted.

The heavy metals and their ores are interspersed throughout the older rocks, in the form of *veins* or *lodes*, which are cracks or fissures of the rock filled up with the ore. Other ores, such as ironstone, are found in the more recent rocky formations, having been deposited in large masses, probably from aqueous solution.

## THE MOST USEFUL METALS.

The most useful metals are *iron*, *lead*, *copper*, *tin*, and *zinc*.

73. *IRON*.—Iron is, of all metals, the most important to mankind. Its uses were long unknown to the human race, the age of iron implements being preceded by the ages of bronze and stone. Pure metallic iron exists only in very small quantity on the earth's surface, almost entirely occurring in meteoric stones.

The process of obtaining iron from its ores requires an amount of knowledge and skill which the early races of men did not possess. The iron of commerce exists in three different forms, exhibiting very different properties, and having different chemical constitutions: (1) *wrought iron*; (2) *cast-iron*; (3) *steel*.

The first is nearly pure iron; the second is a compound of iron with varying quantities of carbon and silicon; and the third a compound of iron with less carbon than is needed to form cast-iron.

Pure iron in the form of powder may be obtained by heating the oxide moderately in a current of hydrogen. The hydrogen combines with the oxygen to form water, leaving the iron free. It must, however, be kept in an atmosphere of hydrogen, as finely divided iron takes fire spontaneously in the air. Iron has a bright white color, and is remarkably tough, though soft. The pure metal crystallizes in cubes. Iron which has been hammered has, when broken, a granular structure; but it becomes fibrous when the iron is rolled into bars, and the more or less perfect form of the fibre determines to a great extent the toughness and the value of the metal. This fibrous texture of hammered bar-iron undergoes a change when

exposed to long continued vibration, the iron returning to its original crystalline condition. Many accidents have occurred in the breaking of railway axles, owing to this change from the fibrous to the granular texture. Wrought iron melts at a very high temperature; but, as it becomes soft at a much lower point, it can be easily worked. When hot, it possesses the peculiar property of *welding*; that is, the power of uniting firmly when two clean surfaces of hot metal are hammered together.

Iron and certain of its compounds are strongly magnetic. The metal loses this power when red-hot, but regains it upon cooling. A solid mass of iron does not oxidize or tarnish in dry air, at the ordinary temperature; but if heated, it oxidizes in black scales. When more strongly heated in the air, or plunged into oxygen gas, it burns with the formation of the same black oxide (II). In pure water, iron does not lose its brilliancy; but, if a trace of carbonic acid is present, and access of air is permitted, the iron soon rusts.

74. *Manufacture of Iron.*—The oldest method of manufacturing wrought iron was to heat the ore in a blast-furnace with charcoal or coal, and to hammer out the spongy mass of iron thus obtained. This plan can only be economically followed on a small scale and with the purest ores, and has been superseded by a more complicated method, applicable to all kinds of iron-ore. The most important ore is an impure carbonate called *clay ironstone*. This is first *roasted* (that is, heated in contact with air) to drive off the carbonic acid, and reduce the iron to an oxide. It is next *smelted* in a *blast-furnace*. These furnaces (Figure 15) are usually about fifty feet high, and about fifteen feet in diameter in the widest part of the cavity *CD*. The lowest part, *F*, is called the *crucible*, or *hearth*. *II* are the *tuyères*, or pipes through which air is forced by powerful bellows.

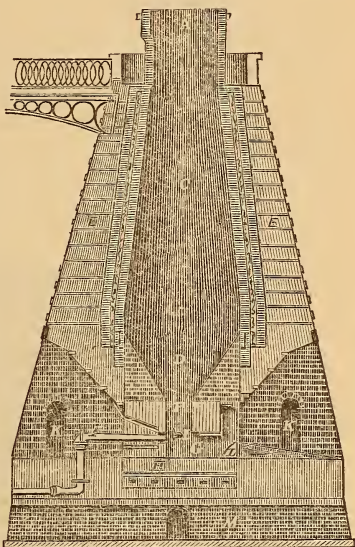
*K*, *K*, and *M* are arched galleries for the convenience of workmen employed about the furnace. When working regularly, the furnace is charged from a door at the end of the gallery near the top, first with coal, and then with a mixture of roasted ore and limestone broken into small pieces. As the fuel burns away and the materials gradually sink, fresh supplies of fuel and of ore are added; so that the furnace is kept filled with alternate layers of each.

The oxygen of the air from the bellows combines with the carbon of the fuel, forming carbonic oxide,  $\text{CO}$ , which rises through the porous mass, and, taking the oxygen from the ore, becomes converted into carbonic acid,  $\text{CO}_2$ . The iron, mixed with the earthy matter of the ore, settles down into the hottest part of the furnace, where both are melted. The iron, being the heavier, sinks to the bottom, where it is drawn off at intervals through a *tap-hole* in the floor *H*. The lighter earthy matter, or *slag*, floats on the surface of the iron, like oil on water, and flows off through an opening above the *tymph-stone* *L*. The limestone aids in liquefying the earthy matter, and unites with it to form the slag.

At this stage the iron is *cast-iron*.

The properties and appearance of cast-iron vary much

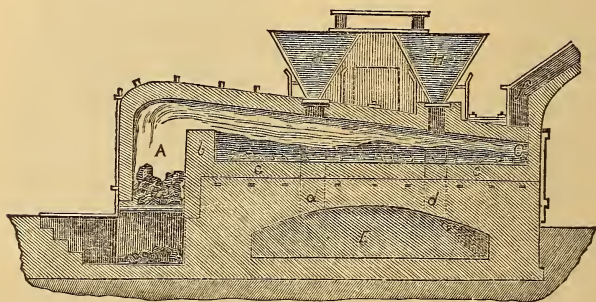
Fig. 15.



with the amount of carbon and silicon which it contains ; for cast-iron is not a definite chemical compound of these elements with iron. The carbon is found in cast-iron, (1) as scales of graphite, giving rise to *mottled* cast-iron ; and (2) in combination, forming *white* cast-iron.

In order to make *wrought iron* from cast-iron, the latter must undergo the processes of *refining* and *puddling*. These consist essentially in burning out the carbon and silicon, by exposing the heated metal to a current of air in a *reverberatory* furnace. Such a furnace is repre-

Fig. 16.



sented in Figure 16. The ore is put into the hoppers *H H*, from which it falls into the chamber *C*, where it is spread out on the *bed c c*. The fuel is burned on a hearth at *A*, separated from the ore by the bridge *b*. The heated gases rising from the burning fuel are *reverberated*, or reflected, by the arched roof of the furnace, and driven down upon the ore, and then pass off through the flue *f*. When the ore is sufficiently roasted, it is allowed to fall through openings, *d d*, into the chamber *E*. The ore is stirred from time to time, to expose fresh surfaces to the action of the air and the flame. The melted cast-iron becomes first covered with a coat of oxide, and gradually thickens, so as to allow of its being rolled into large lumps or balls. During this process, the



whole of the carbon escapes as carbonic oxide, and the silicon becomes oxidized to silica, which unites with the oxide of iron, and forms a fusible slag. Any phosphorus or sulphur contained in the iron is also oxidized in this process. The ball is then hammered, to give the metal coherence, and to squeeze out the liquid slag, and the mass is afterwards rolled into bars or plates.

75. *Steel*.—Steel is formed when bars of wrought iron are heated to redness for some time in contact with charcoal. The bar is then found to have become fine-grained instead of fibrous; the substance is more malleable and more easily fusible than the original bar-iron, and is found to contain carbon varying in amount from one to two per cent. Steel has several important properties, especially the power of becoming very hard and elastic when quickly cooled, which fits it for the manufacture of edge-tools. These are, however, generally made of bar-steel, which has been previously fused and cast into ingots.

A new and very rapid mode of preparing cast-steel is that known as the *Bessemer process*. This process consists in burning out all the carbon and silicon in cast-iron, by passing a blast of atmospheric air through the molten metal, and then adding such a quantity of pure cast-iron to the wrought iron thus prepared as is necessary to give carbon enough to convert the whole mass into steel. The melted steel is then at once cast into ingots. In this way six tons of cast-iron can, at one operation, be converted into steel in twenty minutes. The Bessemer steel is now largely manufactured for railway axles and rails, for boiler-plates, and other purposes, for which it is much better fitted than wrought iron, so that this process bids fair to revolutionize the old iron industry. It has already been put into practice on a large scale in England, France, Belgium, Sweden, and India.



76. *LEAD*.—Lead does not occur free in nature. It is obtained from *galena*, or plumbic sulphide,  $\text{PbS}$ . The galena is roasted in a reverberatory furnace, with the addition of a small quantity of lime to form a fusible slag with any silicious mineral matter present in the ore. By the action of the air, a portion of the sulphide is oxidized to sulphate, while in another portion the sulphur burns off, and plumbic oxide is left behind. After a time, the air is excluded, and the heat of the furnace raised, and the remaining sulphur burns at the expense of the oxygen in the oxide already formed, leaving the lead free.

Lead is a bluish-white metal, and so soft that it may be scratched with the nail. It is quite ductile and malleable, but has little tenacity or elasticity. It melts at  $617^{\circ}$ , and at a higher temperature volatilizes, though not in quantity sufficient to be distilled.

The surface of the metal remains bright in dry air, but it soon becomes tarnished in moist air, owing to the formation of a film of oxide; and this oxidation proceeds rapidly in presence of a small quantity of weak acid, such as carbonic or acetic. In pure water freed from air, lead also preserves its lustre; but, if air be present, plumbic oxide is formed, and as this dissolves slowly in the water, a fresh portion of metal is exposed for oxidation. This solvent action of water upon lead is a matter of much importance, owing to the common use of lead water-pipes, and the peculiarly poisonous action of lead compounds upon the system when taken even in minute quantities for a length of time. The small quantity of certain salts contained in all spring and river waters exerts an important influence on the action of lead. Thus waters containing nitrates or chlorides are liable to contamination with lead, while those *hard* waters containing sulphates or carbonates may generally be brought into contact with lead without danger, as a thin deposit

of sulphate or carbonate is formed, which preserves the metal from further action. If the water contains much free carbonic acid, it should not be allowed to come into contact with lead, as the carbonate dissolves in water containing this substance. The presence of lead in water may easily be demonstrated by acidulating the water, passing a current of hydric sulphide (sulphuretted hydrogen) through a deep column of the liquid, and noticing whether it becomes tinged of a brown color, from the formation of plumbic sulphide.

Lead pipes lined with tin have been recommended for water-pipes; but if the lining is not absolutely perfect, they are more dangerous than ordinary lead pipes. If from defective soldering, or cracks, or breaks in the lining, or from corrosive action, the water comes in contact with the lead, a galvanic action begins, and the lead is more rapidly oxidized than it would be if not joined with the tin.

There is the same danger in the use of the metallic double-lined ice-pitchers. The lining is often made of dissimilar metals, and the parts are joined by a solder containing lead. The thin film of silver is soon worn off upon the interior; galvanic action then promotes corrosive action, and the water becomes poisonous.

On the whole, the best way of protecting lead-pipes from oxidation, is by coating them with sulphide of lead, which is insoluble in water. This can be done by dissolving one pound of potassic sulphide (sulphide of potassium) in two gallons of water, and letting the solution remain in the pipe twelve hours, or until the whole inside is thoroughly blackened. This preventive process is not perfect, but it is very nearly so.

77. *COPPER*. — Copper is an important metal, largely used in the arts. It has been known from very

early times, as it occurs native in the metallic state, and is moreover easily reduced from its ores. Metallic copper is found in enormous quantity near Lake Superior, in North America, and other localities. The following ores are the most important: (1) a compound of copper, sulphur, and iron, known as *copper pyrites*,  $\text{Cu}_2\text{S} + \text{Fe}_2\text{S}_3$ ; (2) the *cuprous sulphide*,  $\text{Cu}_2\text{S}$ ; (3) the *carbonate* or *malachite*; and (4) the *red* or *cuprous oxide*,  $\text{Cu}_2\text{O}$ . Copper is obtained on a large scale from the carbonate or oxide, by reducing these ores, together with carbon and some silica, in a blast-furnace.

Metallic copper has a peculiar deep red color, which is best seen when a ray of light is several times reflected from a bright surface of the metal; it is very malleable, ductile, and tenacious; it melts at a red heat, and is slightly volatile at a white heat, giving a green tint to a flame of hydrogen gas which is passed over it; and it is one of the best conductors of heat and electricity. Copper does not oxidize, either in pure dry or moist air, at ordinary temperatures, but if heated to redness in the air, it is soon converted into cupric oxide.

78. *Alloys of Copper*.—Copper combines with several of the metals to form what are called *alloys*.

*Brass* is an alloy containing about two-thirds of copper and one-third of zinc. It is harder than copper, and can be more easily worked. The addition of from one to two per cent of lead improves the quality of brass for most purposes. The *yellow metal*, used for the sheathing of ships, contains sixty per cent of copper. *Bronze*, *gun-metal*, *bell-metal*, and *speculum-metal* are alloys of copper and tin in varying quantities. They are all remarkable for the property of being hard and brittle when slowly cooled, but of becoming soft and malleable if, when red-hot, they are cooled suddenly by dipping into cold water.

79. *TIN*. — The ores of tin — although this metal has been known from very early times — occur in but few localities, and the metallic tin is not found in nature. The chief European sources of tin are the Cornish mines, where it is found as *tin-stone*,  $\text{SnO}_2$ . It was probably from these mines that the Phœnicians and Romans obtained all the tin which they employed in the manufacture of bronze. Tin-stone is also met with in Malacca and Borneo and Mexico. In order to prepare the metal, the tin-stone is crushed and washed to remove mechanically the lighter portions of rock with which it is mixed, and the purified ore is then placed in a reverberatory furnace, with anthracite or charcoal, and a small quantity of lime. The oxide is thus reduced, and the liquid metal, together with the slag, consisting of calcic silicate, falls to the lower part of the furnace. The blocks of tin, still impure, are then refined by gradually melting out the pure tin, leaving an impure alloy behind.

Tin has a white color resembling that of silver; it is soft, malleable, and ductile, but has little tenacity. When bent, pure tin emits a peculiar crackling sound. It melts at  $442^\circ$ , and is not sensibly volatile. Tin does not lose its lustre on exposure to the air, whether dry or moist, at ordinary temperatures; but if strongly heated, it takes fire, and a white powder of stannic oxide is formed.

Owing to its brilliancy, and its power of resisting ordinary atmospheric changes, tin is largely used for coating iron, copper, and other metals, which are more abundant and more easily oxidized. *Tin plate*, or *sheet tin*, as it is called, is iron thus coated with tin. The thin sheets of iron are thoroughly cleaned with sulphuric acid, and then immersed in melted tin for an hour or so. Copper is tinned by brushing the melted tin over its surface, which must first be made perfectly clean.

Tin is sometimes used for water-pipes; and there is a

popular impression that it is never acted upon by water. In certain localities, however, it oxidizes rapidly, and is soon rendered worthless. The safety of tin pipes, as compared with lead, does not consist in their exemption from corrosive action, but in the harmlessness of the resultant oxides and carbonates.

80. *Alloys of Tin*.—Several alloys of tin, besides those already mentioned (78), are employed in the arts. *Britannia metal* is an alloy of equal parts of brass, tin, antimony, and bismuth. The best *pewter* is an alloy of four parts of tin to one of lead. Common *solder* contains equal parts of tin and lead, and is more fusible than lead.

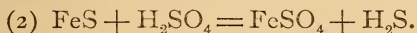
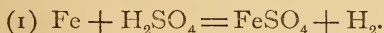
81. *ZINC*.—Zinc is an abundant and useful metal, closely resembling magnesium in its chemical character, but it is much more easily extracted from its ores. The chief ores of zinc are the *sulphide* or *blende*, the *carbonate* or *calamine*, and the *red oxide*. In order to extract the metal, the powdered ore is roasted, to convert the sulphide or carbonate into oxide; the roasted ore is then mixed with fine coal or charcoal, and strongly heated in crucibles or retorts of peculiar shape; the zincic oxide is reduced by the carbon, carbonic oxide gas comes off, and the metallic zinc distils over, and is easily condensed.

Zinc is a bluish-white metal, with a crystalline structure. It is brittle at the ordinary temperature, but when heated to between  $200^{\circ}$  and  $300^{\circ}$ , it may be rolled out or hammered with ease. If more strongly heated, it is again brittle, and may be broken up in a mortar. Zinc melts at  $773^{\circ}$ , and at a bright red heat it begins to boil, and volatilizes; or if air be present, it takes fire, and burns with a greenish flame, forming zincic oxide. Zinc is not acted upon by moist or dry air, and hence it is

largely used in the form of sheets, and is employed as a protecting covering for iron. The sheets of iron are plunged into melted zinc, covered with sal-ammoniac, which keeps the surface of the zinc free from oxide, and allows the two metals to unite. Iron thus coated with zinc is said to be *galvanized*. *German silver* is an alloy of zinc, copper, and nickel.

82. *IRON SALTS*.—The oxides of iron are four in number: (1) *ferrous oxide*,  $\text{FeO}$ , from which the green or ferrous salts are derived; (2) *ferric oxide*,  $\text{Fe}_2\text{O}_3$ , yielding the yellow ferric salts; (3) the *magnetic*, or *black oxide*,  $\text{Fe}_3\text{O}_4$ , which does not form any definite salts; (4) *ferric acid*,  $\text{H}_2\text{FeO}_4$ , a weak acid, forming colored salts with potassium. The ferrous oxide colors glass green, and gives the peculiar tint to common bottle-glass. The most important of the ferrous salts are,—

(1) *Ferrous Sulphate*,  $\text{FeSO}_4$ . This soluble salt, sometimes called *green vitriol*, is obtained by dissolving (1) metallic iron, or (2) ferrous sulphide, in sulphuric acid, or by the slow oxidation of *iron pyrites*,  $\text{FeS}_2$ .



The solution thus obtained yields, on evaporation, large green crystals of the salt. It is largely used in the manufacture of several black dyes, and is one of the constituents of writing ink. Like ferrous oxide, this salt easily takes up oxygen, producing a new salt called *ferric sulphate*.

(2) *Ferrous acetate*, formed by the action of acetic acid on iron, is largely used in dyeing and calico-printing.

Of the ferric salts, the *chloride*,  $\text{Fe}_2\text{Cl}_6$ , is the most



important; it forms in brilliant red crystals when chlorine gas is passed over heated metallic iron.

83. *LEAD SALTS*.—Three compounds of lead and O are known: (1) *Litharge*, or *plumbous oxide*,  $\text{PbO}$ , a straw-colored powder obtained by heating lead in a current of air. It is used in painting and in glass-making, and with acids forms the important lead salts. (2) *Plumbic oxide*,  $\text{PbO}_2$ . (3) *Red oxide*, or *red lead*, a compound of the two last oxides, having the composition,  $2 \text{PbO}$ ,  $\text{PbO}_2$ . It is obtained by exposing litharge to the air at a moderate red heat, oxygen being absorbed. Red lead is used as a paint and in glass-making.

Of the soluble salts of lead, the *nitrate*,  $\text{Pb}_2\text{NO}_3$ , is the most important. This compound is obtained by dissolving the oxide, the carbonate, or metallic lead in warm nitric acid. *Plumbic acetate*, or *sugar of lead*, is also a soluble salt. Almost all the other lead salts are insoluble in water. *Plumbic carbonate*, or *white lead*,  $\text{PbCO}_3$ , is a substance much used in the arts as a paint. The salt may be obtained in the pure state by precipitating a cold solution of the nitrate with an alkaline carbonate, when it falls down as a white powder. For preparing the salt in quantity, two plans are employed: the one similar in principle to that described for the pure salt; and the other an old and interesting process, known as the *Dutch method*. In this process thin sheets of lead are rolled into a coil, and each coil placed in an earthen pot containing a small quantity of crude vinegar, which, however, does not come in contact with the lead. Several hundred of these jars and coils are packed on a floor in a bed of stable manure or spent tan-bark, and then covered with boards, while a second layer of pots similarly charged is placed above, and this is continued until the building is filled. After remaining thus for several weeks,



the coils are taken out, when the greater part of the lead is found to be converted into white carbonate. It appears that a lead acetate is first formed, and that the acetic acid is gradually driven out from its combination by the carbonic acid evolved from the putrefying organic matter, and thus enabled to unite with another portion of the lead lying underneath that which was first attacked.

*Plumbic sulphide*, or *galena*,  $\text{PbS}$ , is found native, and is the chief ore of the metal. It is prepared as a black precipitate by passing sulphuretted hydrogen gas through a solution of a lead salt. Galena has a bright bluish-white metallic lustre. *Plumbic sulphate*  $\text{PbSO}_4$ , is a white insoluble salt, which is found native, and is prepared artificially by adding sulphuric acid to a soluble lead salt. *Plumbic chloride*,  $\text{PbCl}_2$ , is prepared by adding muriatic acid to a strong solution of plumbic nitrate, when a crystalline precipitate of plumbic chloride is formed. It dissolves in about thirty parts of boiling water, separating out in shining needles on cooling. *Plumbic iodide*,  $\text{PbI}_2$ , is precipitated in the form of splendid yellow spangles, when hot solutions of potassic iodide and plumbic nitrate are mixed and allowed to cool. *Plumbic chromate*,  $\text{PbCrO}_4$ , is a yellow insoluble salt, generally known as *chrome yellow*, and much used as a paint.

84. *COPPER SALTS*.—Copper forms two oxides, *cuprous oxide*,  $\text{Cu}_2\text{O}$ , and *cupric oxide*,  $\text{CuO}$ . Cuprous oxide imparts to glass a ruby color. Cupric oxide is soluble in acids, and forms a series of salts. The most important of the soluble salts are *cupric sulphate*,  $\text{CuSO}_4$ , and *cupric acetate*, or *verdigris*. The former is often called *blue vitriol*, and is largely manufactured by dissolving copper or its oxide in sulphuric acid. It is used in calico-printing, and in making *Scheele's green*, or *cupric arseniate*, and other paints.

As many of the vegetable acids act upon copper so as to form poisonous salts, copper or brass vessels should never be used for cooking unless they are lined with tin.

85. *SALTS OF ZINC*.—Zinc forms but one oxide,  $\text{ZnO}$ , which is much used as a white paint. Its most important salt is *zincic sulphate*, or *white vitriol*, which is used in calico-printing.

86. *SALTS OF TIN*.—Tin forms two oxides, the *stannous*,  $\text{SnO}$ , and the *stannic*,  $\text{SnO}_2$ . *Stannous chloride*,  $\text{SnCl}_2$ , formed by dissolving tin in muriatic acid, is termed *tin salts* in commerce; it is largely manufactured for the calico-printer and dyer, who use it as a *mordant*; that is, to *fix* the color in the fibre of the cloth, so that it will not wash out. *Potassic stannate* (*stannate of potash*),  $\text{K}_2\text{SnO}_3$ , formed by boiling stannic oxide with soda, is used in the same way. *Stannic chloride*,  $\text{SnCl}_4$ , is also used by dyers, and is prepared for this purpose by dissolving tin in cold nitro-muriatic acid. Of the sulphides of tin,  $\text{SnS}$ , *stannous sulphide*, and  $\text{SnS}_2$ , *stannic sulphide*, are the most important; the former is blackish-gray, and the latter a bright yellow crystalline powder, known as *mosaic gold*.

## NOBLE METALS.

The noble metals are *mercury*, *silver*, *gold*, and *platinum*. They are so called because they do not *rust*, that is, combine with the oxygen of the air at ordinary temperatures.

87. *MERCURY*.—The chief ore of mercury is the sulphide, or *cinnabar*, which occurs at Almaden in Spain, at Idria in Illyria, in California, and also in China and

Japan. The metal is easily obtained by roasting the ore, when the sulphur burns off, and the metal volatilizes, and its vapor is condensed in earthen pipes. Mercury is the only metal liquid at the ordinary temperature; it freezes at  $-39^{\circ}$ ; in the solid state it is malleable and possesses a density of 14.4. It boils at  $662^{\circ}$ , and gives off a slight amount of vapor at the ordinary temperature. Mercury, when pure, does not tarnish in moist or dry air; but when heated above  $700^{\circ}$ , it rapidly absorbs oxygen; and it combines directly with chlorine, bromine, iodine, and sulphur. Mercury is largely used in extracting gold and silver from their ores, and for many other purposes.

Mercury dissolves many of the metals, forming *amalgams*. The most important of these is the amalgam of tin and mercury, used for silvering mirrors. "In order to apply it to the glass, a sheet of tinfoil is spread evenly upon a smooth slab of stone, which forms the top of a table carefully levelled, and surrounded by a groove, for the reception of the superfluous mercury. Clean mercury is poured upon the tinfoil, and spread uniformly over it with a roll of flannel; more mercury is then poured on till it forms a fluid layer of the thickness of about half a crown; the surface is cleared of impurities by passing a linen cloth lightly over it; the plate of glass is carefully dried, and its edge being made to dip below the surface of the mercury, is pushed forward cautiously; all bubbles of air are thus excluded as it glides over and adheres to the surface of the amalgam. The plate is then covered with flannel, weights are placed upon the glass, and the stone is gently inclined so as to allow the excess of mercury to drain off; at the end of twenty-four hours it is placed upon a wooden table, the inclination of which is increased from day to day until the mirror assumes a vertical position: in about a month it is sufficiently drained to allow the mirror to be framed."—MILLER.

88. *SILVER*.—Silver was known to the ancients. It is found in the native state, as well as combined with sulphur, antimony, chlorine, and bromine. It is also contained in small quantities in galena, and it can be extracted with profit from the lead prepared from this ore, even when the lead contains only two or three ounces of silver to the ton. The method thus adopted for the extraction of the silver depends upon the fact that the whole of the silver can be concentrated into a small portion of lead by crystallization; metallic lead free from silver separates out in crystals, and a rich alloy is left. When this reaches the concentration of 300 oz. of silver to the ton, the alloy undergoes the operation of *cupellation*, in which the mixture is melted in a furnace on a porous bed of bone-earth, and a blast of air blown over the surface. The lead oxidizes, and the oxide (litharge) fuses, and partly runs away and partly sinks into the porous bed of the furnace, while the silver remains behind in the metallic state.

For the extraction of silver from the other ores, a process termed *amalgamation* is employed, in which mercury is used to dissolve the metallic silver. The argentiferous ores of Germany, in which the silver occurs in combination with sulphur, are roasted in a furnace with common salt, by which means the sulphide is converted into chloride; the mixture is then placed in casks made to revolve, and scrap-iron and water are added. The iron reduces the silver to the metallic state, and when this is fully accomplished, metallic mercury is added; this forms a liquid amalgam with the silver (and gold, if any be present), and, by distilling the mercury off, the silver is obtained in an impure state. Silver has a bright white color and a brilliant lustre, which it does not lose in pure air at any temperature. When melted in the air, it possesses the singular power of absorbing

mechanically a large volume (twenty-two times its bulk) of oxygen; this gas it again gives out on solidifying.

Silver is probably the best conductor of heat and electricity known, and is extremely ductile. Sulphur combines at once with silver, forming a black sulphide; silver articles long exposed to the air tarnish from this cause. It is because they contain a small quantity of sulphur that eggs, mustard, and horseradish blacken silver spoons. Where coal-gas is used, silver articles not unfrequently tarnish, owing to the fact that the sulphuretted hydrogen has not been thoroughly removed in the purification of the gas.

89. *GOLD*.—Gold is usually found in the metallic state. It occurs in veins in the older rocks, and in the sands of most rivers, and, although generally found in small quantities, it is a widely diffused metal. In order to obtain the gold, the *detritus* or sand which contains the metal is washed in a *cradle* or other arrangement, by means of which the lighter particles of mud or mineral are washed away, while the heavier grains of gold sink to the bottom of the vessel. When gold has to be worked in the solid rock, the mineral is crushed to powder and then shaken up with mercury, and the gold thus extracted by amalgamation.

Gold has a brilliant yellow color, and, in thin films, transmits green light; it is nearly as soft as lead; it can be drawn out into fine wire, and is the most malleable of all the metals. It does not tarnish at any temperature, in dry or moist air; nor is it, like silver, affected by sulphur. It is not acted upon by any single acid (except *selenic*), but dissolves in presence of free chlorine and in nitro-muriatic acid. At high temperatures, gold is slightly volatile. The gold used for coin is an alloy of gold and copper, in the proportion of 11 parts of gold to

1 of copper. This alloy is harder and more fusible, but less ductile, than pure gold. The purity of gold is commonly expressed in *carats*. Pure gold is said to be 24 *carats fine*; an alloy containing  $\frac{23}{24}$  of pure gold is called 23 *carats fine*;  $\frac{18}{24}$  of pure gold (the finest usually employed for jewelry), 18 *carats fine*; and so on.

90. *PLATINUM*.—Platinum is a comparatively rare metal, which always occurs in the native state, and generally alloyed with five other metals; namely, *palladium*, *rhodium*, *iridium*, *osmium*, and *ruthenium*. This alloy occurs in small grains in detritus and gravel in Siberia and Brazil.

The original mode of obtaining the metal was to dissolve the ore in aqua-regia (nitro-muriatic acid), and precipitate the platinum (together with several of the accompanying metals) with sal-ammoniac, as the insoluble double chloride of ammonium and platinum,  $2\text{NH}_4\text{Cl}, \text{PtCl}_4$ . This precipitate, when heated, yields metallic platinum in a finely divided or spongy state; and this sponge, if forcibly pressed and hammered when hot, gradually becomes a coherent metallic mass, the particles of platinum welding together, when hot, like iron. A new mode of preparing the metal has recently been proposed, the ore being melted in a very powerful furnace, heated with the oxy-hydrogen blow-pipe. In this way a pure alloy of platinum, iridium, and rhodium is formed, the other constituents and impurities of the ore being either volatilized by the intense heat, or absorbed by the lime of which the crucible is composed. This alloy is in many respects more useful than pure platinum, being harder and less easily attacked by acids.

Platinum has a bright white color, and does not tarnish under any circumstances in the air. It is extremely infusible, and can only be melted by the heat of the oxy-



hydrogen blowpipe. It dissolves in aqua-regia, but is not acted upon by the ordinary acids, and hence platinum vessels are much used in the laboratory. Caustic alkalies, however, act upon the metal at high temperatures. When finely divided, metallic platinum has the power of condensing gases upon its surface in a remarkable degree. When a mixture of oxygen and hydrogen is brought in contact with spongy platinum, the heat developed by the condensation of the gases is sufficient to ignite them.

91. *SALTS OF MERCURY*.—Mercury forms two oxides, the *mercurous*,  $\text{Hg}_2\text{O}$ , and the *mercuric*,  $\text{HgO}$ , and two corresponding classes of salts. The *mercuric sulphide*,  $\text{HgS}$ , is known as *cinnabar*, or *vermilion*, much used as a paint. *Mercurous chloride*,  $\text{Hg}_2\text{Cl}_2$ , or *calomel*, and *mercuric chloride*,  $\text{HgCl}_2$ , or *corrosive sublimate*, are used in medicine. The bromides and iodides of mercury are used in photography.

92. *SALTS OF SILVER*.—Silver forms two oxides,  $\text{Ag}_4\text{O}$ , *argentic suboxide*, and  $\text{Ag}_2\text{O}$ , *argentic oxide*. The latter is the base of the ordinary silver salts. *Argentic nitrate*,  $\text{AgNO}_3$ , is the most important soluble salt of silver. It is obtained in the form of large transparent tabular crystals, on evaporating a solution of silver in nitric acid. It fuses easily on heating; and when cast into sticks, goes by the name of *lunar caustic*. This salt undergoes decomposition when exposed to the sunlight in contact with organic matter, and a black substance, probably the suboxide, is formed; hence it is employed in the manufacture of *indelible ink* for marking linen and other fabrics.

Of the insoluble silver salts, the *chloride*,  $\text{AgCl}$ , is the most important. This salt occurs in nature, and is then known as *horn silver*. It is precipitated as a white



curdy mass, when a solution of a chloride and a silver salt are brought together. When exposed to the light, the white chloride becomes tinted of a purple color, which increases in shade as the action of light continues. This coloration arises from a partial decomposition of the salt, a small quantity of subchloride and free muriatic acid being formed. In presence of organic matter this change takes place much more rapidly, and upon this fact the art of *photography* depends. Argentic chloride is easily soluble in a solution of sodic hyposulphite, and it is for this reason that the latter salt is used for *fixing* photographic pictures, that is, dissolving out the unaltered silver salt, and thus rendering the image permanent. *Argentic bromide*,  $\text{AgBr}$ , is also acted upon by the light, and is soluble in ammonia and an alkaline hyposulphite. The *iodide*,  $\text{AgI}$ , is a yellow powder, insoluble in water and ammonia, but dissolved by an alkaline hyposulphite.

The *cyanide*,  $\text{AgCN}$ , as well as other salts of silver, is used in electro-plating.

93. *SALTS OF GOLD*.—Gold forms two oxides, the *aurous*,  $\text{Au}_2\text{O}$ , and the *auric*,  $\text{Au}_2\text{O}_3$ . Neither of these oxides forms salts with acids, but the latter unites with bases to form salts called *aurates*. *Auric chloride*,  $\text{AuCl}_3$ , obtained by dissolving gold in aqua-regia, and *auric cyanide*,  $\text{Au}(\text{CN})_3$ , are the most important salts of gold, being used in electro-gilding and photography.

94. *SALTS OF PLATINUM*.—Platinum forms two oxides, the *platinous*,  $\text{PtO}$ , and the *platinic*,  $\text{PtO}_2$ . *Platinic chloride*,  $\text{PtCl}_4$ , is the most important platinum compound. It is obtained as a yellowish-red solution, by dissolving the metal in aqua-regia. It is used in electro-platinizing.

## LESS USEFUL METALS.

The less useful metals are *sodium*, *magnesium*, *aluminium*, *antimony*, *bismuth*, and *nickel*. These are little used in a metallic state, though their compounds are of the highest importance.

55. *SODIUM*.—This metal was discovered by Sir H. Davy, by the decomposition of soda with the galvanic current. It can be procured by reducing the carbonate in presence of carbon, and is now manufactured in considerable quantities for the preparation of other metals, especially magnesium and aluminium. Sodium is a silver-white metal, soft at ordinary temperatures, and melting at  $207^{\circ}$ ; it volatilizes below a red heat, yielding a colorless vapor. The compounds of sodium are very widely diffused, being contained in every speck of dust. They exist in enormous quantities in the older rocks; but they are most readily obtained from sea-water, which contains nearly 3 per cent of sodic chloride (common salt), or from the large deposits of this substance which occur in the form of rock-salt.

96. *MAGNESIUM*.—This metal occurs in large quantities in combination with lime and carbonic acid, in *dolomite* or mountain limestone, and also in sea-water and certain mineral springs, as chloride and sulphate. The metal itself has only recently been prepared in quantity. It is best obtained by heating magnesian chloride with metallic sodium, sodic chloride and metallic magnesium being formed. This metal is of a silver-white color, and fuses at a low red heat. It is volatile, and may be easily distilled at a bright red heat. When soft, it can be pressed into wire, and with care it may be

cast like brass; although, when strongly heated in the air, it takes fire, and burns with a dazzling white light, with the formation of its only oxide, *magnesia*,  $\text{MgO}$ . The light emitted by burning magnesium wire is distinguished for its richness in chemically active rays, and is therefore employed as a substitute for sunlight in photography. It is coming to be used for purposes of illumination.

97. *ALUMINIUM*.—This metal occurs in large quantities, combined with silicon and oxygen, in *felspar* and all the older rocks, and also in *clay*, *marl*, *slate*, and in many crystalline minerals. Metallic aluminium is obtained by passing the vapor of aluminic chloride over metallic sodium. It has recently been manufactured on a large scale, both in England and France, and from its lightness (specific gravity 2.6), its tenacity, and its bright lustre, it has been used for optical purposes as well as for ornamental work. Some of its alloys, as *aluminium bronze*, promise to become of great value in the arts.

98. *ANTIMONY*.—Metallic antimony occurs native, but its chief ore is the *trisulphide*,  $\text{Sb}_2\text{S}_3$ . The metal is easily reduced, by heating the sulphide with about half its weight of metallic iron, when ferrous sulphide and metallic antimony are formed. Antimony may also be reduced by mixing the ore with coal, and heating in a reverberatory furnace. Antimony is a bright bluish-white metal. It is very brittle, and can readily be powdered in a mortar. It melts at about a red heat, and may be distilled at a white heat, in an atmosphere of hydrogen. Antimony undergoes no alteration in the air at ordinary temperatures, but rapidly oxidizes if exposed to air when melted; and if heated more strongly, it takes fire, and burns with a white flame, giving off dense white fumes of

oxide. Antimony is not attacked either by dilute muriatic or sulphuric acid; but nitric and nitro-muriatic acid dissolve it easily. The alloys of antimony are largely used in the arts. Of these, *type-metal* (an alloy of lead and antimony) is the most important; it contains from 17 to 20 per cent of the latter metal.

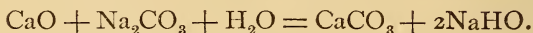
99. *BISMUTH*.—This metal is found in small quantities in the native state, but occurs more often as a sulphide; it is easily reduced to the metallic state, and then exhibits a pinkish-white color. It melts at  $507^{\circ}$ , and is volatilized at a white heat. Bismuth does not oxidize in dry air at the ordinary temperature; but if heated strongly, it burns with a blue flame, forming an oxide; it also takes fire when thrown into chlorine gas. Bismuth dissolves easily in nitric acid. The metal is chiefly used as an ingredient of *fusible metal*. The alloy of 2 parts of bismuth; 1 of lead, and 1 of tin, melts at  $201^{\circ}$ ; that of 8 parts of bismuth, 5 of lead, and 3 of tin, melts at  $212^{\circ}$ . The compounds of bismuth are used in the porcelain manufacture, in medicine, and as cosmetics.

Both bismuth and antimony closely resemble arsenic in the compounds which they form. Thus we have  $\text{Sb}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_5$ , and  $\text{H}_3\text{Sb}$ ;  $\text{Bi}_2\text{O}_3$  and  $\text{Bi}_2\text{O}_5$  (67). Hence bismuth and antimony are now generally classed among the *non-metallic* elements of the *nitrogen group*.

100. *NICKEL*.—Nickel occurs in large quantities combined with arsenic, as *kupfernickel*; also together with cobalt in *speiss*; and it is now prepared in considerable quantities for the manufacture of *German silver*, an alloy of nickel, zinc, and copper. Nickel is a white, malleable, and tenacious metal; it melts at a somewhat lower temperature than iron, and is strongly magnetic, but loses this property when heated to above  $600^{\circ}$ .

101. *SALTS OF SODIUM*.—There are two compounds of sodium and oxygen,  $\text{Na}_2\text{O}$ , *sodic oxide*, and  $\text{Na}_2\text{O}_2$ , *sodic peroxide*. Sodic oxide has a strong affinity for water, with which it combines to form  $\text{NaHO}$ , *sodic hydrate* (*caustic soda*). This is a white solid, very soluble in water, very caustic and alkaline, and is largely used in making soap.

Caustic soda is now manufactured on a very large scale, by boiling lime and sodic carbonate (carbonate of soda) with water, and evaporating down the clear solution. The reaction is as follows:—



102. *Sodic Chloride*.—Sodic chloride,  $\text{NaCl}$ , is *common salt*. It is from this compound that nearly all the other sodic compounds are prepared.

In Southern Europe, on the shores of the Mediterranean, large quantities of salt are obtained from seawater. The water is allowed to flow into large shallow pools, called *salt-pans*, where it is evaporated by the agency of the air and the sun. Only pure water passes off in the form of vapor, and the solution grows more and more concentrated. After a time, the brine is pumped into large iron pans, and evaporated by artificial heat until the salt crystallizes.

In many parts of the earth there are salt lakes, often called *seas*. The streams flowing into them are more or less impregnated with salt, which they dissolve from the soil over which they flow. Such lakes are natural salt-pans, for the water which is evaporated from them is pure, and they consequently become more and more saturated with salt, till it is finally deposited on the bottom in solid crystals. The most remarkable of these lakes is the Great Salt Lake in Utah.

Such salt lakes appear to have existed in all geological

ages, and by long-continued evaporation to have given rise to large masses of solid salt, called *rock salt*. These beds of rock salt are found in all parts of the earth. The most remarkable are at Wieliczka in Poland, and at Cardona in Spain. The former is 500 miles long, 20 miles broad, and 1,200 feet deep. It has been worked for several centuries. Some of the galleries excavated in it are 30 miles long. The bed at Cardona is a "mountain of salt," 400 or 500 feet high, and the salt is of the greatest purity.

Salt is obtained from these beds sometimes by excavation and sometimes by solution. In the latter case, a hole is sometimes bored down to the bed of salt, often to the depth of 1,200 or 1,500 feet. A tube somewhat smaller than the bore is then introduced, and fresh water allowed to flow down outside the tube. This water, on reaching the bed, becomes saturated with salt, and rises in the tube. Since, however, it is heavier than fresh water, it will not rise to a level with the latter on the outside of the tube. If the bore is 1,200 feet deep, the brine will rise within about 200 feet of the top. It must be pumped up the remaining distance. The solution is then evaporated, and solid salt obtained.

It not unfrequently happens that natural springs occur in such localities that their waters come into contact with beds of salt. Such springs are called *salt springs*, or *brine springs*. They sometimes come to the surface; but oftener they can only be reached by boring, and the brine brought to the surface by means of the pump. The water of these natural springs is usually less concentrated than that of the artificial springs described above. In England and in this country the salt produced is nearly all obtained from brine springs.

The most important salt springs of this country are in Central New York, in Virginia, and in Pennsylvania.



About 6,000,000 bushels of salt are produced annually in New York. When the brine is not a saturated solution, it is usually concentrated by partially evaporating it in large shallow pans by the air and the sun. It is then further concentrated and crystallized by artificial heat.

103. *Sodic Carbonate*.—Sodic carbonate,  $\text{Na}_2\text{CO}_3$ , is known in commerce as *soda-ash*, and is manufactured on an enormous scale. It is largely used in glass-making, soap-making, bleaching, and many other processes in the arts.

Before the French Revolution, the Continental nations of Europe derived their soda-ash mainly from Spain, where it was made from the ashes of certain marine plants, which contain a large amount of soda. The soda-ash thus obtained was called *barilla*.

In England, the soda-ash used was mainly obtained from the ashes of a sea-weed called *kelp*, which grows abundantly on the north and west coast of Ireland, and on the west coast and the islands of Scotland.

One of the first effects of the war of the French Revolution was to cut off the supply of alkali from Spain. About this time, a French chemist, Le Blanc, discovered a process by which sodic carbonate, or soda-ash, could be obtained from common salt, or *sodic chloride*,  $\text{NaCl}$ . This process became publicly known through a commission appointed, during the first year of the Republic, to investigate the subject of alkali manufacture.

Le Blanc's method is the same as that now used in the making of sodic carbonate, which has come to be one of the most important branches of chemical manufacture. The process may be divided into two stages:—

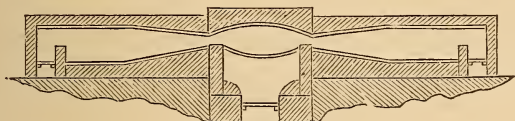
(1) Manufacture of sodic sulphate, or *salt-cake*, from sodic chloride; called the *salt-cake process*.

(2) Manufacture of sodic carbonate, or soda-ash, from salt-cake; called the *soda-ash process*.

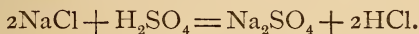


(1) *Salt-cake Process*. — This consists in the decomposition of salt, by means of sulphuric acid. This is effected in a furnace, called the *salt-cake furnace*, a section of which is represented in Figure 17. It consists

Fig. 17.



of a large covered iron pan, placed in the centre of the furnace, and heated by a fire placed underneath; and two *roasters*, or reverberatory furnaces, placed one at each side, on the hearths of which the salt is completely decomposed. The charge of half a ton of salt is first placed in the iron pan, and the sulphuric acid allowed to run in upon it. Hydric chloride (muriatic acid) is evolved, and escapes through a flue with the products of combustion into towers, or *scrubbers*, filled with coke or bricks moistened with a stream of water; the acid vapors are thus condensed, while the smoke and heated air pass up the chimney. The reaction is as follows:—



After the mixture of salt and acid has been heated for some time in the iron pan, and has become solid, it is raked out upon the hearths of the *roasters*, where the flame and heated air of the fire complete the decomposition into sodic sulphate and hydric chloride.

(2) *Soda-ash Process*. — This consists (1) in the preparation of the sodic carbonate, and (2) in the separation and purification of the same. The first chemical change which the salt-cake undergoes is its reduction to sodic *sulphide*, by heating it with powdered coal:—



The second decomposition is the conversion of the sodic sulphide into sodic carbonate, by heating it with chalk or limestone (calcic carbonate) : —



These two reactions are, in practice, carried on at once; a mixture of 10 parts of salt-cake, 10 parts of chalk or limestone, and 7.5 parts of coal, being heated in a reverberatory furnace, called the *balling furnace*, until it fuses, and the decomposition is complete, when it is raked out into iron wheelbarrows to cool. This process is generally called the *black-ash process*, from the color of the fused mass.

The next operation consists in the separation of the sodic carbonate from the insoluble calcic sulphide and other impurities. This is easily accomplished by *lixivation*, or dissolving the former salt out in water. On evaporating down the solution, for which the waste heat of the balling furnace is used, and calcining the residue, the soda-ash of commerce is obtained.

No less than 200,000 tons of common salt are annually consumed in the alkali works of Great Britain, for the preparation of nearly the same weight of soda-ash, the value of which is about \$10,000,000.

104. *Bicarbonate of Soda*. — The salt known as *bicarbonate of soda*,  $\text{HNaCO}_3$ , is obtained by exposing the crystallized sodic carbonate in an atmosphere of carbonic acid. It is a white crystalline powder, used in medicine and for making effervescing drinks; also in bread-making, as a substitute for yeast.

105. *Other Sodic Salts*. — *Sodic nitrate* (*soda salt-petre*),  $\text{NaNO}_3$ , is found in northern Chili in large beds. It is used in making nitric acid, and as a manure.

*Sodic sulphate* (*sulphate of soda*),  $\text{Na}_2\text{SO}_4$ , is familiarly known as *Glauber's salts*.

*Sodic hyposulphite* (*hyposulphite of soda*) is used in photography (92).

*Sodic borate*, or *borax*, is considerably used in the arts, especially as a *flux* in soldering. It dissolves the oxide formed upon the surfaces to be united, and thus keeps them clean and bright.

*Sodic silicate* (*silicate of soda*) is called *soluble glass*, and is used to some extent as a paint or varnish for fixing fresco colors, and for preserving stone-work, and quite largely in calico printing and dyeing.

106. *SALTS OF MAGNESIUM*.—Magnesium has but one oxide,  $MgO$ , or *magnesia*. The most important salt of this oxide is the *magnesian sulphate* or *Epsom salts*, used in medicine.

107. *SALTS OF ALUMINIUM*.—The only oxide of aluminium is *alumina*,  $Al_2O_3$ . It occurs native in a nearly pure and crystalline state as *corundum*, *ruby*, *sapphire*, and *emery*. Alumina is largely used as a  *mordant* in dyeing and calico-printing, as it has the power of forming insoluble compounds, called *lakes*, with vegetable coloring-matter, and thus fixes the color in the pores of the cloth so that it cannot be washed out (86).

The soluble aluminic sulphate,  $Al_2(SO_4)_3$ , is prepared on a large scale for the use of the dyer, by decomposing clay by the action of sulphuric acid. The solid mixture of silica and aluminic sulphate thus obtained goes by the name of *alum-cake*. The most useful compounds of alumina are, however, the *alums*, a series of double salts, which aluminic sulphate forms with the alkaline sulphates. *Common potash alum* has the composition  $K_2Al_2(SO_4)_4$ . It may be prepared by dissolving the two sulphates together, and allowing the compound salt to crystallize, but it is usually obtained from the decomposi-

tion of a shale or clay containing iron pyrites,  $\text{FeS}_2$ . This substance gradually undergoes oxidation when the shale is roasted (taking oxygen from the air), producing sulphuric acid, which unites with the alumina of the clay, and, on the addition of a potassic compound, alum crystallizes out. A salt called *ammonium alum*, and containing  $\text{H}_4\text{N}$ , instead of K, is at present prepared on a large scale; the ammonia liquor of the gas-works, together with sulphuric acid, being added to the burnt shale, instead of a potash salt.

There are several other alums known, in which *iron*, *chromium*, or *manganese* takes the place of the *aluminium* in common or potash alum.

*Clay* is an *aluminic silicate* resulting from the disintegration and decomposition of felspar by the action of air and water. *Kaolin* or porcelain clay is the purest form of clay, containing no iron or other impurities. There are many very beautifully crystalline minerals, as *garnet* and *mica*, consisting of aluminic silicates combined with silicates of other metals.

108. *Glass, Porcelain, and Earthen-ware.* — The silicates of the alkalis are soluble in water and non-crystalline; those of the *alkaline earths* (Ba, Sr, and Ca), are soluble in acid and crystalline; while compounds of the two are insoluble in water and acids, and do not assume a crystalline form. Such a compound, when fused, is termed a *glass*. There are four different kinds of glass used in the arts, differing in their chemical composition, and exhibiting corresponding differences in their properties: (1) *Crown* or *window* and *plate glass*, composed of silicates of soda and lime; (2) *Bohemian glass*, consisting of silicates of potash and lime; (3) *flint glass* or *crystal*, containing silicates of potash and lead; and (4) common green *bottle-glass*, composed of silicates of soda, lime, iron, and alumina. The first and third of these

kinds of glass are easily fusible, while the second or potash glass is much less fusible; the addition of plumbic oxide increases the specific gravity and lustre of the glass as well as its fusibility. The common glass articles of household use are generally made of flint glass, while for chemical apparatus a soda-lime glass is to be preferred. The potash-lime glass is much employed where an infusible or hard glass is needed. The fourth kind of glass is an impure mixture of various silicates, employed for purposes in which the colors and fineness of the glass are not of consequence.

In the preparation of all the fine qualities of glass, great care is requisite in the selection of pure materials, as well as in the processes of manufacture. Generally the materials are melted together with a quarter to a half their weight of *cullet*, or broken glass of the same kind. After the glass articles have been blown or cast, they must be *annealed*, that is, made less brittle by being very slowly heated and as slowly cooled in an oven arranged for the purpose.

Certain metallic oxides have the power of *coloring* glass when they are added in small quantity. Thus ferrous oxide produces a deep green color (bottle-glass), while the oxides of manganese impart a purple tint to glass. Advantage is taken of this in the preparation of colorless glass, for as it is difficult to obtain materials perfectly free from iron, which imparts a green color, a small quantity of black oxide of manganese is added to the mixture, and the violet color thus produced neutralizes the green, and a nearly colorless glass is the result. The addition of arsenious oxide effects the same end by oxidizing the ferrous to ferric oxide. The colors of precious stones are imitated by adding certain oxides to a brilliant lead glass called *paste*; thus the blue of the sapphire is given by a small quantity of cobaltic oxide,

while cuprous oxide imparts a ruby-red color, and ferric oxide a yellow color resembling topaz.

The various forms of *porcelain* and *earthen-ware* consist of aluminic silicate or clay in a more or less pure state, covered with some substance which fuses at a high temperature, and forms a *glaze*, giving a smooth surface and binding the material closely together, and thus filling up the pores of the baked clay. For the manufacture of porcelain the finest *kaolin* or China clay is used, while for common earthen-ware an inferior clay may be employed. The glaze used for porcelain is generally finely powdered felspar, the *biscuit*, or porous ware, being first dipped into a vessel containing this substance suspended in water and then strongly heated. The articles thus coated can be used for chemical purposes, as this glaze withstands the action of acids. For earthen-ware the so-called *salt glaze* is used; obtained by throwing some common salt into the furnaces containing the strongly heated ware. The salt is volatilized and undergoes decomposition on the heated surface, depositing a fusible silicate upon it, and rendering the ware impervious to moisture.

109. *SALTS OF ANTIMONY*. — Antimony has two oxides,  $\text{Sb}_2\text{O}_3$ , and  $\text{Sb}_2\text{O}_5$ , and two corresponding sulphides and chlorides. The most important of its salts is *tartar-emetica*, or *tartrate of antimony and potash*, used in medicine.

110. *SALTS OF BISMUTH*. — Bismuth forms two oxides, analogous to those of antimony. The most important of the salts is the *nitrate*,  $\text{Bi}_3\text{NO}_3$ , which is easily procured by dissolving the metal in nitric acid.

111. *SALTS OF NICKEL*. — There are two



oxides of nickel,  $\text{NiO}$ , and  $\text{Ni}_2\text{O}_3$ . The former of these gives rise to salts which have a peculiar apple-green color. The latter is a black powder, prepared by adding a solution of bleaching-powder to a soluble nickel salt. The most important soluble salt is the *nitrate*,  $\text{Ni}_2\text{NO}_3$ .

## METALS NOT USED IN A FREE STATE, BUT VALUABLE FOR THEIR SALTS.

There are certain metals which are not used in a free state, but which form salts of considerable importance. These metals are *potassium*, *calcium*, *strontium*, *barium*, *manganese*, *chromium*, and *cobalt*.

112. *POTASSIUM*.—This metal was discovered in the year 1807, by Sir Humphrey Davy, who decomposed potash by means of a powerful galvanic current. Before this time the alkalies and alkaline earths were supposed to be elementary bodies. The metal is now prepared by heating together potash and carbon to a high temperature in an iron retort.

Potassium is a bright, silver-white metal, which can be easily cut with a knife at the ordinary temperature; it is brittle at  $32^\circ$ , and melts at  $144^\circ$ . It rapidly absorbs oxygen when exposed to the air, and becomes converted into a white oxide.

The original source of potassic compounds is in the felspar of the granitic rocks, as these contain from .02 to .03 of this metal. Up to the present time, no cheap and easy mode has been found of separating the potash from the silicic acid with which it is combined in felspar. Plants, however, are able slowly to separate out and assimilate the potash from these rocks and soils; so that, by burning the plant and leaching the ashes with water, soluble potash-salt is obtained.



This is the crude potassic carbonate, called, when purified by crystallization, *pearlash*. It is the substance from which most of the potassic compounds are obtained.

The most important compounds of potassium are *caustic potash*,  $\text{KHO}$ , *potassic carbonate* (*carbonate of potash*),  $\text{K}_2\text{CO}_3$ , and *potassic nitrate*, or *saltpetre*,  $\text{KNO}_3$ . This last compound readily parts with its oxygen, and is therefore extensively used in making *gunpowder* and fireworks.

*Gunpowder* consists of an intimate mixture of saltpetre, charcoal, and sulphur. When the gunpowder is ignited, the sulphur and charcoal burn at the expense of the oxygen in the saltpetre, while the nitrogen is set free. It is to the expansive force of the large volume of gases suddenly set free in a confined space, that the destructive power of gunpowder is due.

*Potassic chlorate*,  $\text{KClO}_3$ , gives up its oxygen even more readily than the nitrate, and is used, as we have seen, in the preparation of oxygen (10). It is also used in making fireworks and percussion caps.

113. *CALCIUM*. — Calcium forms a considerable portion of the rocks of which the earth is composed, and occurs in very large quantities, forming whole mountain chains of *chalk*, *gypsum*, and *limestone*. The metal is obtained by the decomposition of the chloride by the electric current, or by heating the iodide with sodium. It is a light, yellow metal, which easily oxidizes in the air. When heated in air, it burns with a bright light, forming *lime*,  $\text{CaO}$ , the only oxide of calcium.

*Lime* is prepared on a large scale for building and other purposes, by heating limestone (the carbonate) in kilns by means of coal mixed with the stone; the carbonic acid escapes, and *quicklime* or *caustic lime* remains. Pure lime is a white, infusible substance, which

combines with water very readily, giving off great heat, and falling to a white powder called *calcic hydrate*, or *slaked lime*. The hydrate is slightly soluble in water, 1 part of it dissolving in 730 parts of cold, but only in 1,300 parts of boiling water, and forming lime-water, which, like the hydrate, has a great power of absorbing carbonic acid from the air. It is indeed partly owing to this property that the hardening or *setting* of mortars and cements made from lime is due. *Mortar* consists of a mixture of slaked lime and sand. A gradual combination of the lime with the silica occurs, and this helps to harden the mixture. *Hydraulic cement*, which hardens under water, is prepared by carefully heating an impure lime containing clay and silica; a compound silicate of lime and alumina appears to be formed on moistening the powder, which then solidifies, and is not acted upon by water. Lime is largely used in agriculture, its action being, (1) to destroy the excess of vegetable matter contained in the soil; and (2) to liberate the potash for the use of the plants from heavy clay soils by decomposing the silicate.

*Calcic carbonate* (*carbonate of lime*)  $\text{CaCO}_3$  occurs most widely diffused, as chalk, limestone, coral, and marble; many of those enormous deposits being made up of the microscopic remains of minute sea-animals. The carbonate is almost insoluble in pure water; but readily dissolves when the water contains carbonic acid, and is deposited again, in crystals, as the gas escapes. In this way enormous masses of crystalline limestone are formed. Water charged with carbonic acid and calcic carbonate makes its way through the roof of limestone caverns, and, as the carbonic acid gradually escapes, the calcic carbonate is deposited in dependent masses, like icicles, termed *stalactites*; while the water, falling on the floor of the cavern before it has parted with all its

carbonic acid and dissolved limestone, deposits a fresh portion of the crystalline matter, and thus a new growth, or *stalagmite*, gradually rises to meet the *stalactite* which hangs from the roof. In this way a natural pillar of limestone is formed.

*Calcic sulphate*,  $\text{CaSO}_4$ , occurs in nature, combined with  $2\text{H}_2\text{O}$ , as *gypsum* or *alabaster*. It is soluble in 400 parts of water, and is a very common impurity in spring water, giving rise to a *hardness* which cannot be removed by boiling. Gypsum, when moderately heated, loses its water, and is then called *plaster of Paris*; this, when moistened, takes up two atoms of water again and *sets* to a solid mass, and is therefore much used for making casts and moulds.

*Calcic chloride* (*chloride of calcium*),  $\text{CaCl}_2$ , is formed when limestone or marble is dissolved in muriatic acid; if the solution be then evaporated, colorless needle-shaped crystals are obtained. When these are dried, they form a porous mass which takes up moisture with great avidity, and is much used for drying gases.

114. *STRONTIUM*.—This element occurs in much smaller quantities than calcium, being found in only a few minerals. It likewise occurs in minute quantities in certain spring waters. The metal has a yellowish-white color, and is prepared by the action of a current of electricity on the fused chloride. It resembles calcium closely in its properties. When heated in the air, it burns, forming the oxide *strontia*.

The native salts of strontium, the *carbonate* and *sulphate*, are insoluble, and serve for the preparation of the remaining salts. The *nitrate*,  $\text{Sr}_2\text{NO}_3$ , and the *chloride*,  $\text{SrCl}_2$ , are soluble in water. These are the only salts of this metal which are employed in the arts. They are used for the preparation of *red fires*, as the volatile

salts of strontium have the power of coloring the flame crimson.

115. *BARIUM*.—Barium compounds occur somewhat more widely dispersed than those of strontium, the two most common barium minerals being the *sulphate*, or *heavy spar*, and the *carbonate*, or *witherite*. The metal barium has not yet been obtained in the coherent state; but the metallic powder may be prepared in the same way as calcium and strontium, which it closely resembles in its properties.

The most important barium compounds are the *chloride* and the *nitrate*, used as tests for sulphuric acid, and for giving a green color to the flame in fireworks.

116. *CHROMIUM*.—Chromium is a substance whose compounds do not occur very widely distributed, or in large quantities. They are, nevertheless, much used in the arts as pigments, many of them having a fine bright color. The chief ore of this metal is a compound of the oxides of chromium and iron, called *chrome iron-stone*, found in America, Sweden, and the Shetlands. A compound of chromium, lead, and oxygen, called *plumbic chromate* (*chromate of lead*), is also found. Pure chromium appears to be the most infusible of all the metals, as it cannot be melted at a temperature sufficient to fuse and volatilize platinum.

Chromium forms three oxides: *chromous oxide*,  $\text{CrO}$ , *chromic oxide*,  $\text{Cr}_2\text{O}_3$ , and *chromic peroxide*,  $\text{CrO}_3$ , which, dissolved in water, has a strong acid reaction, and may then be called *chromic acid*. It neutralizes bases, and forms yellow or red salts, called *chromates*. The most common of these are known as the *chromate* and *bichromate* of *potash*,  $\text{K}_2\text{CrO}_4$  and  $\text{K}_2\text{Cr}_2\text{O}_7$ . The former is a yellow salt, and the latter a red salt, which

is made on a large scale, and used in the preparation of the various chrome pigments.

The chief of the insoluble chromates is *plumbic chromate*,  $\text{PbCrO}_4$ , or *chrome yellow*, obtained by precipitating a potassic chromate by a soluble lead salt, and largely used for dyeing and other purposes.

117. *COBALT*.—Cobalt is never found in a free state except in small quantities in meteoric iron. It is almost as infusible as iron. It is of a reddish-gray color, hard, and strongly magnetic. It is not used in a metallic state, but many of its compounds are remarkable for the beauty of their colors, and are used as pigments. It forms two oxides,  $\text{CoO}$  and  $\text{Co}_2\text{O}_3$ . The *zaffre* of commerce is a very impure oxide of cobalt, mixed with two or three times its weight of sand. It is used for coloring glass. *Thenard's blue*, or artificial *ultramarine*, is a compound of cobaltic and aluminic oxides.

118. *MANGANESE*.—Manganese occurs in nature as an oxide, and it can be obtained, though with difficulty, in the metallic state, by heating the oxide very strongly with charcoal. The metal is of a reddish-white color; it is brittle, and hard enough to scratch glass. It decomposes water at the ordinary temperature with evolution of hydrogen; it cannot be preserved in the air without undergoing oxidation, and must be kept under naphtha, or in a sealed tube; it is slightly magnetic, and, like iron, combines with carbon and silicon. Metallic manganese is not used in the arts; but an alloy of this metal and iron is now made on a large scale, and used in the manufacture of steel. Some of its oxides are used for evolving chlorine from muriatic acid, and also for giving glass a purple color.

Manganese forms several well-marked oxides: (1) *man-*

*ganous oxide*,  $\text{MnO}$ , a basic body, furnishing a series of salts; (2) *manganic oxide*,  $\text{Mn}_2\text{O}_3$ , which also forms salts, but of a much less stable character; (3) *black oxide*,  $\text{MnO}_2$ , a neutral substance, occurring as an ore of manganese; (4) and (5) two acid oxides, which give rise to salts known as *manganates* and *permanganates*.

Black oxide of manganese is found in many parts of Europe; but the most productive mines are in Thuringia and Moravia. More than 18,000 tons are used annually in England in the manufacture of bleaching powder.

## THE RARER METALS.

The other metallic elements are very rare substances, and as yet are of very little practical importance.

119. *Cadmium* (Cd) is a white metal resembling tin, and is found in small quantities in the ores of zinc. It is remarkable for forming very fusible alloys. For example, an alloy of 15 parts of bismuth, 8 of lead, 4 of tin, and 3 of cadmium, melts at about  $140^\circ \text{F}$ . The *sulphide* is a valuable yellow pigment, and the *iodide* is used to some extent in photography.

120. *Iridium* (Ir) is the heaviest of the metals. An alloy of iridium and osmium is very hard, and is used for the points of gold pens. It forms three oxides, which readily pass one into another, giving rise to the variety of tints which characterize the solution of its salts. It is because of these changes of color that the metal is called *iridium*, from *iris*, the rainbow.

121. *Tungsten*, or *wolfranium* (W), forms with steel an alloy of remarkable hardness.  $\text{WO}_3$ , or *tungstic acid*, combines with sodium to form *sodic tungstate* (*tungstate of soda*),  $\text{Na}_2\text{WO}_4$ , which is used in calico-printing, and in combination with starch to render linen and cotton fabrics incombustible.



122. *Uranium* (U) forms an oxide,  $\text{UO}$ , which gives a peculiar yellow color to glass, and also renders it *fluorescent*.

The other metals are of too little use or interest to be mentioned here.

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### SUMMARY.

The metals are seldom found in a free state, but usually combined with other elements as *ores*. Their separation from these ores is called *reduction*.

The most useful metals are iron, lead, copper, tin, and zinc.

The noble metals are gold, silver, mercury, and platinum.

The less useful metals are sodium, magnesium, aluminium, antimony, bismuth, and nickel.

The metals not used in a free state, but valuable for their salts, are potassium, calcium, strontium, barium, manganese, chromium, and cobalt.

Among the rarer metals, cadmium, iridium, tungsten, and uranium are of some interest.

Among the most important *metallic compounds* may be mentioned: salt, soda-ash, soda saltpetre, caustic soda, bicarbonate of soda, pearlash, saltpetre, caustic potash, lime, alum, glass, porcelain, green vitriol, blue vitriol, white vitriol, litharge, red lead, and white lead.



## CHEMISTRY OF THE ATMOSPHERE.

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### COMBUSTION.

123. *Composition of the Atmosphere.*—We live at the bottom of an aerial ocean called the *atmosphere*, which is some fifty miles in depth. This atmosphere contains free oxygen; as may be shown by inverting a jar of it over a jar of nitric oxide. The gases, on mixing, become cherry-red (33).

Burn a piece of phosphorus in a jar of air over water. The jar is filled with dense white fumes, which are soon absorbed by the water, which rises and partially fills the jar. Introduce now some nitric oxide into the jar while still over the water, and the gas shows no trace of red color. The free oxygen then can be removed from the air by burning phosphorus in it. After all the oxygen has combined with the phosphorus, and the compound formed has been absorbed by the water, the jar is found to be about one-fifth filled with water; showing that about one-fifth of the air is oxygen.

The gas remaining in the jar is found to be almost pure nitrogen.

Besides the oxygen and nitrogen, there is a small quantity of *carbonic anhydride* (carbonic acid); as may be shown by passing a large volume of air through lime-water. There is also *watery vapor*, which is continually condensed in the form of rain and dew. A trace of *ammonia*, and of *nitric acid*, is also found; and to

these are to be added the exhalations continually rising from the earth. The whole quantity of these minor ingredients, with the exception of watery vapor, does not amount to more than one part in a thousand. The proportions of oxygen and nitrogen are almost invariable, while those of the other ingredients are continually fluctuating.

It must be borne in mind that the atmosphere is not a chemical compound, but merely a *mixture* of these different gases. "Indeed, we may regard the globe as surrounded by at least three separate atmospheres, — one of oxygen, one of nitrogen, and one of aqueous vapor, — all existing simultaneously in the same space, yet each entirely distinct from the other two, and only very slightly influenced by their presence."

The following Tables are from Miller: —

*Composition of the Atmosphere.*

Oxygen . . . . .	20.61
Nitrogen . . . . .	77.95
Carbonic Acid . . . . .	.04
Watery Vapor (average) . . . . .	1.40
	<hr/>
	100.00

*Composition in Tons.*

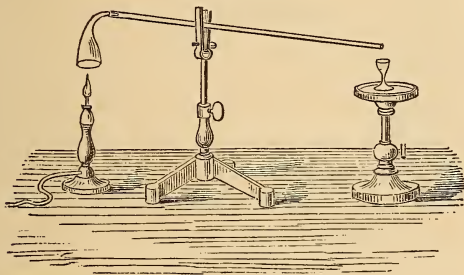
Oxygen . . . . .	1,233,010	billions of tons.
Nitrogen . . . . .	3,994,593	" "
Carbonic Acid . . . . .	5,287	" "
Watery Vapor . . . . .	54,460	" "

124. *The Products of the Burning of a Candle or Coal-Gas are Carbonic Acid and Water.* — When a lighted taper is held to a candle, or to a jet of coal-gas, the latter takes fire. In what does its burning consist?

Invert a bottle for a short time over the candle or gas-burner ; then remove it, pour in a little lime-water, close the mouth of the bottle with the hand, and shake it. The lime-water becomes milky-white ; showing that *carbonic acid* has been produced by the burning.

If the candle or gas be burnt under a tin funnel connected with a long glass tube (which must be kept cold), moisture will collect on the inside, and, after a short time, will trickle down, and drop from the end of the tube. When potassium is put into water, it burns with a rose-colored flame. If the liquid from the tube be tested with a bit of potassium, it proves to be water, which is therefore another product of the burning.

Fig. 18.



No other substance is produced, except in very minute quantities, by the burning of the candle or the gas.

125. *The Candle, in Burning, removes Oxygen from the Air.*—Arrange a candle, so that it can be covered with a bell-jar, over the water-trough ; then light it, and cover it with the jar. It soon ceases to burn, and the water rises in the jar. The burning, then, removes something from the air.

Put a lighted candle into air from which the oxygen has been removed, and it is at once extinguished ; showing that it cannot burn without oxygen. It must then be *oxygen* which it removes from the air when it burns.

126. *All ordinary Combustion consists in the Combination of the Oxygen of the Air with the burning Substance.*—We have seen that carbonic acid,  $\text{CO}_2$ , and water,  $\text{H}_2\text{O}$ , are the products of the burning of a candle. Of the three elements in these products, the O, as we have seen, comes from the air; the C and H exist in the candle.

The force, then, which causes the candle to burn, is *affinity*, and the burning is the combination of the oxygen of the air with the elements of the candle.

Experiments similar to those which we have tried with the candle, will show that any ordinary combustible substance removes oxygen from the air when it burns, and that it cannot burn without oxygen. We conclude, then, that all ordinary combustion is the combination of the oxygen of the air with the burning body.

127. *Why a Draft is necessary in Stoves and Furnaces.*—We see now why our stoves and furnaces must have a draft. As fast as the oxygen is taken from the air by the burning fuel, this air must be removed, and a fresh supply must take its place. In other words, a stream of air must be kept constantly flowing over or through the fuel.

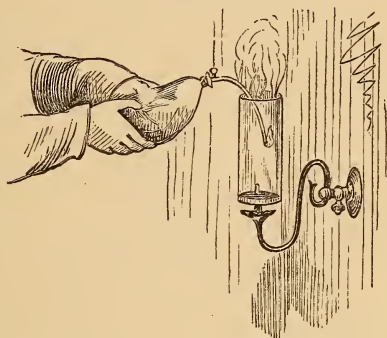
We see, also, how the fire can be regulated by means of the draft. If the doors or dampers through which the air is admitted be partially closed, the supply of air will be diminished, and the burning will therefore be retarded.

128. *Combustibles and Supporters of Combustion.*—Any substance, as coal-gas, which can be made to burn, is called a *combustible*; while any substance, as air or oxygen, in which it can burn, is called a *supporter of combustion*. These terms are convenient, though, strictly speaking, the one substance is no more a combustible or a supporter of combustion than the other. Since the

burning of coal-gas consists in the combination of the gas with oxygen, the oxygen in reality burns, as well as the gas; and, on the other hand, the gas is as much a supporter of the combustion as the oxygen. The burning must of course take place where the gases come together. A jet of oxygen would appear to burn in an atmosphere of coal-gas, just as a jet of coal-gas appears to burn in an atmosphere of oxygen.

Fit a cork to one end of a lamp chimney, and let the tip of a gas-burner pass through it, as represented in the figure. Allow the gas to escape for some time, and then light it at the top of the chimney. It will burn quietly, and the chimney will evidently be filled

Fig. 19



with coal-gas. Fill a gas-bag with oxygen, and fasten to the bag a bent glass tube drawn out into a fine jet. Force the oxygen through the tube in a gentle stream, and introduce the end of the tube through the flame into the chimney. As it passes the flame, the oxygen takes fire, and burns brightly in the coal-gas; the oxygen apparently becoming the combustible body, and the coal-gas the supporter of combustion.

In both the flames which we have here, it will be seen that gases are burning where they come together;—the coal-gas and the oxygen of the air, where they meet at the top of the chimney; the oxygen from the bag and the coal-gas, where they meet at the end of the tube inside the chimney.

129. *Oxygen must be Heated before it will combine with ordinary Combustibles.*—The jet of coal-gas has no disposition to burn until a lighted taper is applied to it. The oxygen of the air is at all times in contact with wood and coal, yet they do not burn unless they are first kindled. When even as inflammable a gas as hydrogen is mixed with oxygen, it does not burn unless ignited with a taper or an electric spark. “At the ordinary temperature of the air its chemical affinities are dormant; and, although endowed with forces which are irresistible when in action, it awaits the necessary conditions to call them forth. One of the grandest works of ancient art which have come down to us, is the colossal statue of the Farnese Hercules. The hero of ancient mythology is represented in an erect form, leaning on his club, and ready for action; but at the moment every one of the well-developed muscles of his ponderous frame is fully relaxed, and the figure is a perfect ideal of repose, yet a wonderful embodiment of power. Here in this antique we have most perfectly typified the passive condition of oxygen, the hero of the chemical elements. Raise now the temperature to a red heat, and in a moment all is changed. The dormant energies of its mighty powers are aroused, and it rushes into combination with all combustible matter, surrounded by those glorious manifestations of light and heat which every conflagration presents.”—COOKE.

130. *Combustion is Self-sustaining.*—It is not necessary to arouse any large amount of oxygen to activity in order to insure the continuance of the combustion. When, for instance, a lighted match is held to the wick of a candle, it excites but a few molecules of oxygen to activity. These few rush into combination with the elements of the candle, and by so doing develop sufficient heat to awaken the activity of more oxygen, which in



turn enters into combination and develops more heat. In this way a supply of active oxygen is maintained until the candle is consumed.

The slowness of combustion depends upon the fact, that the oxygen is mixed with the inert nitrogen in such proportions as generally to "restrain the awakened energies of the fire-element within the narrow limits which man appoints."

131. *The Point of Ignition.*—Different substances begin to burn at very different temperatures. This is well illustrated in the kindling of a coal-fire. Shavings are put into the grate first, then kindling-wood, then charcoal, and finally hard coal. The shavings are lighted by means of a match. The match is a bit of dry, soft wood, one end of which is covered with sulphur and tipped with phosphorus. It is a well-known fact, that when two bodies are rubbed together, heat is developed. On striking the match, sufficient heat is developed by the friction to ignite the phosphorus, which takes fire at a temperature of about  $150^{\circ}$  Fahrenheit. The phosphorus in burning develops heat enough to ignite the sulphur, which burns at a temperature of about  $500^{\circ}$ . The burning sulphur develops heat enough to ignite the wood of the match; the match, to ignite the shavings; the shavings, the kindling-wood; the kindling-wood, the charcoal; and the charcoal, the hard coal, which requires the temperature of a full white heat to set it on fire.

132. *The Products of Combustion are not always Gaseous.*—In the burning of coal-gas and of a candle, the products are wholly gaseous, and in the burning of wood they are mainly gaseous; but when metals, as copper and iron, burn in oxygen, the products of their combustion are *solid*.

133. *Magnesium and some other Metals will burn in the Air.*—A magnesium wire will burn brightly in the

air (96). Calcium, also, burns readily in the air (113), as aluminium (97) does, if pulverized and strongly heated.

It will be noticed that all these elements are rare in their free state. Many of the rare metals, as potassium, sodium, magnesium, and calcium, are as combustible as carbon; but they differ from carbon in giving rise to solid products while burning.

134. *Oxygen is not the only Supporter of Combustion.*—If a piece of gold-leaf or Dutch foil be dropped into a jar of chlorine, it vanishes in a flash of light (53). Here the burning consists in a combination with chlorine. Tin and copper foil and pulverized antimony will also burn in chlorine. Many metals will burn in the vapor of sulphur; the burning being then a combination of the metal with sulphur.

135. *The Materials of the Earth's Crust are chiefly Chemical Compounds.*—We have seen that when marble is acted upon by muriatic acid (42) we obtain *carbonic acid*,  $\text{CO}_2$ , and *calcic chloride*,  $\text{CaCl}$ . The calcium, carbon, and oxygen of these compounds must come from the marble, or *calcic carbonate*,  $\text{CaCO}_3$ .

We find, then, in marble two very combustible substances, calcium and carbon, combined with oxygen. Limestone has the same composition. Calcium, then, which is a very great rarity in a free state, is a very abundant element in nature.

It has been found that the rocks and solid matter of the earth are made up chiefly of such combustible elements as potassium, calcium, magnesium, aluminium, and carbon, combined with oxygen. Many of the rarest and most costly metals, then, are the most abundant in nature. The fact that they are so rare in a free state is due to their extreme combustibility. It is very difficult to separate them from oxygen, and no less difficult to keep them separate.

136. *The Present Materials of the Earth are Products of Combustion.*—We see, then, that water, the most abundant of liquids, is made up of the very combustible elements, hydrogen and oxygen; while the solid materials of the earth are composed chiefly of the very combustible elements, potassium, magnesium, calcium, aluminium, carbon, and silicon, in combination with oxygen. These materials are the products of combustion. There must have been a time when these elements existed together in a free state. Then, by some means unknown to us, the mass took fire; and the conflagration raged until all the materials were consumed. There was more oxygen than was needed for the combustion; and this is now found in the air in a free state. Oxygen was the most abundant of all the elements, since it alone makes up half the weight of the solid earth, eight-ninths the weight of the water, and one-fifth the weight of the atmosphere.

The diagram below (from Cooke) illustrates what has been said of the composition of the earth. It will be seen, that, of the 65 elements, 13 alone make up at least .99 of its known mass, while the other 52 do not constitute altogether more than .01.

Oxygen. $\frac{1}{2}$	Silicon. $\frac{1}{4}$
	Aluminium. Magnesium. Calcium.
	K Na Fe C
	S H Cl N   52 others.

## SLOW COMBUSTION.

137. *Partially Active Condition of Oxygen.*—We have seen (11, 12) that, besides its active and passive states, oxygen exists in a third, or intermediate, condition, in which it is *partially* active. In this form it plays a very important part in nature. It acts silently and slowly, taking months, and even years, to accomplish its work ; but the results “far surpass in true grandeur those dazzling displays of power which the fire-element manifests when fully aroused.”

138. *Decay.*—When wood, or any other *organic* substance (that is, any compound of *vegetable* or *animal* origin) is exposed to moist air, it *decays*. It first becomes rotten, and then slowly disappears. This decay consists in a gradual union of the substance with oxygen ; in other words, a *slow combustion*. A log of wood which rots in the forest undergoes the very same change as one which is burnt on the hearth ; the sole difference being, that, while the latter burns up in a few hours, the former is consumed only after the lapse of many years.

Wood, like other vegetable compounds, consists mainly of carbon, hydrogen, and oxygen. When it burns on the hearth, its carbon and hydrogen combine with the oxygen of the air, forming carbonic acid and water, which pass off in the smoke. The hydrogen is more combustible than the carbon, and therefore burns first, leaving the carbon in the form of glowing coals. These are consumed in their turn, gradually smouldering away, until nothing is left but a little ashes.

Quite the same process is going on with the decaying log in the forest. In decay, as in burning, the hydrogen of the wood unites with the atmospheric oxygen sooner than the carbon does ; hence, in this stage of its decay, the wood becomes darker, and more like charcoal. At

length, both the hydrogen and the carbon are burnt; and the log is slowly converted into carbonic acid and water, leaving only a handful of earth as the *ashes* of this lingering combustion. Even the *heat* generated in this form of burning is found to be precisely the same as in ordinary combustion; the only difference being that, in the latter case, it is all set free in a few hours, while in the former it is so slowly developed that it escapes our notice.

139. *Causes of Decay.*—Green wood decays much sooner than dry wood. Indeed, if wood be kept perfectly dry, it will not decay for ages. In the dry climate of Egypt, wooden mummy-cases have been preserved for more than three thousand years.

The decay of the green wood is due to the presence of what are called *albuminous* substances. The most important of these is *vegetable albumen*, and it is essentially the same thing as the albumen (or *white*) of an egg. We have said that most vegetable substances are made up of carbon, hydrogen, and oxygen; but these albuminous compounds, which form only a small part of the bulk of plants, contain an additional element, *nitrogen*. We have seen that the compounds of nitrogen are generally very unstable, and these albuminous substances are peculiarly so. In the presence of moisture they soon *putrefy*, or break up into simpler compounds. The oxygen of the air takes no part in this process, but, by contact with the putrefying substance, it is, in some mysterious way, awakened to the state of partial activity mentioned above. It is thus enabled to attack and consume the wood and all the other organic compounds present. The decay, or slow combustion, once begun, is self-sustaining; fresh portions of oxygen being continually roused to activity by the process itself, precisely as in ordinary burning (130).

When the nitrogenized vegetable compounds are *burnt*, the nitrogen passes off in a *free* state; when they *decay*, combined with hydrogen as *ammonia*.

140. *Rusting*.—The slow combustion of metals is called *rusting*, and the oxide formed is called *rust*. All the familiar metals, except silver, gold, and platinum, are tarnished on exposure to the air; that is, they become covered with a film of rust, or oxide.

That *heat* is developed by rusting, as by other kinds of slow combustion, is shown by the fact that if a large pile of iron-filings be moistened and exposed to the action of the air so that they rust rapidly, the temperature rises perceptibly.

A remarkable case of heat developed by rusting occurred in England during the manufacture of a submarine electric cable. The copper wire of the cable was covered with gutta-percha, tar, and hemp, and the whole enclosed in a casing of iron wire. The cable, as it was finished, was coiled in tanks filled with water: these tanks leaked, and the water was therefore drawn off, leaving about 163 nautical miles of cable coiled in a mass 30 feet in diameter (with a space in the centre 6 feet in diameter) and 8 feet high. It rusted so rapidly that the temperature in the centre of the coil rose in four days from 66° to 79°, though the temperature of the air did not rise above 66° during the period, and was as low as 59° part of the time. The mass would have become even hotter, had it not been cooled by pouring on water.

141. *Spontaneous Combustion*.—When charcoal which has been finely pulverized for making gunpowder is exposed in large heaps, the oxygen of the air combines with it slowly at first; but, as the heat developed accumulates, the oxidation becomes more rapid, until in some cases the mass takes fire and burns.

So too, when cotton or tow, which has been used for



wiping machinery, and has become saturated with oil, is laid aside in heaps, it begins to oxidize slowly; but the heat developed makes the combustion more and more rapid, until sometimes the heap bursts into a flame.

This rapid combustion, developed gradually from slow combustion, is called *spontaneous combustion*.

142. *Respiration*. — The albuminous or *nitrogenized* compounds, which form but a small part of the plant, make up almost the entire bulk of the animal, so that animal substances are even more prone to decay than vegetable. And this decay is not confined, as we might suppose, to *dead* animal matter, but is constantly going on in the *living* animal. The only difference is, that in the latter case the loss from decay is continually repaired, while in the former case it is not. The materials for the repair of the living body are furnished by the *food*.

This food is mainly made up of three classes of substances: (1) *non-nitrogenized*, as starch and sugar; (2) *nitrogenized*, as lean meat; and (3) *fatty* substances, as butter. All three kinds are absolutely necessary to the life of man. They are all contained in *milk*, which may be regarded as "the type of animal food." It contains *sugar*, which belongs to the first of the above classes; *caseine*, or *curd*, which belongs to the second; and *butter*, which belongs to the third. Bread also contains all three kinds of food; being made up of (1) *starch*, (2) *gluten* (the most important nitrogenized constituent of wheat and other grain), and (3) a small quantity of *oil*. A man cannot live for any length of time on any one kind of food, as starch or butter, or on any mixture of kinds of food, which does not contain all three classes of substances.

The different classes of food serve different purposes in the body. The *nitrogenized* and a part of the *fatty* substances supply the waste which results from the action

of the varied machinery of the body. They renew the muscles, sinews, and nerves, which are constantly wearing out. On the other hand, the non-nitrogenized substances, as starch and sugar, probably take no part in repairing the machinery, but merely furnish fuel to keep up the heat of the body. To produce heat they must be burnt up, and we shall see that the process is another example of *slow combustion*.

Starch and sugar make up by far the greatest part of this fuel, and in fact of our food generally. They are almost identical in composition, and starch can readily be converted into sugar. When taken into the stomach, starch undergoes this change, and the sugar then readily dissolves in the water present. The solution is absorbed by the veins, and becomes mingled with the blood, which carries it to the heart. By the heart, which is made up of two force-pumps, the blood is forced through the lungs. These are composed of millions of little membranous bags or *air-cells*, closely packed together, and all connected by means of tubes with the windpipe, and thus with the nose and mouth. The membrane of the cells is very thin, so that they are easily compressed. The whole mass of the lungs is also very elastic, and by the action of muscles they are alternately expanded and contracted as we breathe. When they expand, the air from without rushes in and fills the cells; and when they contract, this air is forced out again.

We have said that the blood charged with sugar is forced through the lungs. The tube, or *artery*, which conveys it, divides and subdivides, until it is reduced to very small capillary tubes, which form a delicate network on the surfaces of the air-cells. The walls of these capillaries are very thin, and the oxygen of the air readily passes through them, by a process called *osmose*, and mingles with the blood. At the same time, and in the

same way, carbonic acid is given out by the blood, and mixes with the air. The blood, holding in solution both sugar and oxygen, now goes back to the heart; and by the second force-pump it is sent to all parts of the body. In the mean time, the sugar is burnt up by the oxygen which was absorbed in the lungs.

“Sugar, like wood, consists of carbon, hydrogen, and oxygen. The last two are present in the proportions to form water, so that sugar may be said to be composed of charcoal and water. Of these two substances the charcoal only is combustible. This, during the circulation of the blood, is slowly burnt up by the dissolved oxygen, and converted into carbonic acid, which remains in solution until it is discharged, when the blood returns again to the lungs, or else escapes through the skin.”\*

Respiration, then, is a kind of combustion, in which “the fuel is sugar, and the smoke carbonic acid and aqueous vapor.” The presence of carbonic acid in the air, from the lungs, may be proved by breathing through a glass tube into lime-water, which soon becomes milky. The presence of the watery vapor may be shown by breathing upon any cold substance.

The weight of carbonic acid breathed out by a full-grown man, in a day, varies from 1 to 3 pounds, or from 9 to 27 cubic feet; and the weight of carbon burnt is from 5 to 15 ounces. The amount of heat produced is of course the same as would be set free by burning the same weight of charcoal in a stove. The temperature of the body is thus kept above that of the air; the heat

\* Cooke’s “Religion and Chemistry.” The greater part of §§ 137-139 and 142-144, has been condensed from the 3d and 4th Lectures in this admirable series. We cannot too strongly commend the book to teachers. They will be certain to draw from it, for the purposes of oral instruction, far more largely than our limits have permitted here.

of the blood, even in the coldest climate, being maintained at  $96^{\circ}$ .

“In regulating the temperature of his body, man follows instinctively the same rules of common sense which he applies in warming his dwellings. In proportion as the climate is cold, he supplies the loss of heat by burning more fuel in his lungs, and hence the statements of arctic voyagers, who have told us that twelve pounds of tallow-candles make only an average meal for an Esquimaux, are not inconsistent with the deductions of science.”

143. *Slow and Rapid Combustion of Sugar.*—We may compare the rapid combustion of sugar in air with its slow combustion in the body, by the following experiment: Take 2 ounces of pulverized sugar, or the average quantity burnt in the body of a man in an hour, and mix it with  $5\frac{1}{2}$  ounces of pulverized potassic chlorate. We have then the sugar and the solidified oxygen of the chlorate mingled as in the blood; but the oxygen is passive, and will not combine with the sugar, until roused to activity. A single drop of sulphuric acid let fall upon the mixture serves to awaken its dormant energy; and the mass is consumed in an instant, with intense evolution of heat and light. The amount of heat concentrated in this momentary burst of flame is no greater than would have been generated in the blood in the course of an hour.

“The splendid displays of combustion arrest our attention by their very brilliancy, while we overlook the silent yet ceaseless processes of respiration and decay, before which, in importance and magnitude, the greatest conflagrations sink into insignificance. These are but the spasmodic efforts of nature; those, the appointed means by which the harmony and order of creation are preserved.”

144. *The Daily Consumption of Oxygen in Nature.*

—“Faraday has roughly estimated that the amount of oxygen required daily, to supply the lungs of the human race, is at least one thousand millions of pounds; that required for the respiration of the lower animals is at least twice as much as this, while the always active processes of decay require certainly no less than four thousand millions of pounds more, making a total aggregate of seven thousand millions of pounds required to carry on these processes of nature alone. Compared with this, the one thousand millions of pounds which, as Faraday estimates, are sufficient to sustain all the artificial fires lighted by man, from the camp-fire of the savage to the roaring blaze of the blast-furnace, or the raging flames of a grand conflagration, seem small indeed.

*Amount of Oxygen required Daily.*

Whole population . . . . .	1,000,000,000
Animals . . . . .	2,000,000,000
Combustion and fermentation . .	1,000,000,000
Decay and other processes . .	4,000,000,000

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Oxygen required daily . . = 8,000,000,000 lbs.

“How utterly inconceivable are these numbers, which measure the magnitude of nature’s processes,—eight thousand millions of pounds of oxygen consumed in a single day! When reduced to tons, the number is equally beyond our grasp; for it corresponds to no less than 3,571,428 tons. If such be the daily requisition of this gas, will not the oxygen of the atmosphere be in time exhausted? It is not difficult to calculate approximately the whole amount of oxygen in the atmosphere. It is equal to about 1,178,158 thousand millions of tons; a supply which, at the present rate of consumption, would last about nine hundred thousand years.”

## THE GROWTH OF PLANTS.

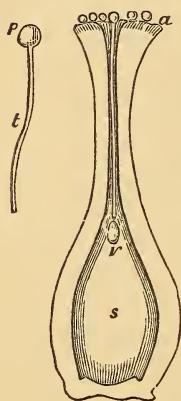
145. *The Embryo Plant in the Seed.*—How do plants grow? How does the tiny seed become the leafy herb? How does the little acorn develop into the giant oak? We shall get the best answer to these questions by tracing a plant through its whole growth.

The seed is formed in the flower, the essential parts of which are the *stamens* and the *pistil*. The *stamens* bear the *anthers*, and these contain the *pollen*. The pistil is in the centre of the flower. It encloses in its *ovary* the *ovules*, which, when ripened, become *seeds*.

In the ripe seed we find the *embryo*, which is a miniature plant with stem and leaves. How has this embryo been formed?

At a certain time a little cavity is formed in the centre of the ovule within the pistil. This cavity is called the

Fig. 20.



*embryo sac*, and is marked *s* in Figure 20. Within this sac, at its upper end, we see a minute body or *vesicle*, *v*. This is the first germ of the embryo; but in order that it may begin its development, it must be acted upon by the pollen. This we see in the form of small grains, *a*, resting on the top of the pistil. It has fallen from the anthers, and lodged here; and now it sends out a very fine and delicate tube, the *pollen-tube*, which pierces the tissue of the pistil, and extends itself until it reaches the vesicle, *v*. Its contact with this microscopic particle of

matter has the mysterious power of making it begin to *grow*, and thus form the embryo.

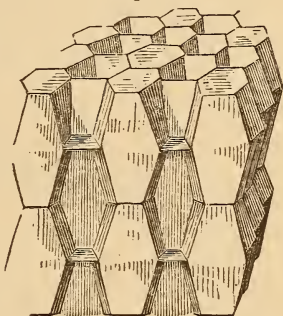
The vesicle is at first a single *cell*; that is, a mem-



branous globule, filled with liquid, in which minute particles can sometimes be discerned. After it has been acted upon by the pollen-tube, it enlarges somewhat, and a partition forms across its interior, dividing it into two cells. Each of these grows and divides in like manner, and thus a cluster of cells is formed. After a time the mass begins to take a definite shape. One end becomes the *radicle*, or the beginning of the *root* of the plant; and the other divides into two parts, which develop into the *cotyledons*, or *seed-leaves*. It is now a perfect embryo, a miniature plant, with root, stem, and leaves, but still shut up in the seed.

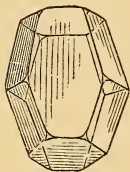
146. *The Plantlet*.—The growth of the plant in the seed, and out of the seed, is essentially the same process. The same division and multiplication of cells continues, and all the parts of the plant are formed by the clustering or *aggregation* of these cells. The cells are too minute to be distinguished with the naked eye, but the microscope shows them in every portion of the plant. Figure 21 shows a thin slice of a rootlet, cut crosswise and lengthwise, as it appears when highly magnified. We see that the whole structure is *cellular*; that is, made up of cells crowded together. A single cell is represented in Figure 22. The natural shape of the cell is spherical; but when cells are clustered or crowded together, they compress one another into the shape in which we see them in these figures. Where they are not thus squeezed, they are generally found to be spheres, more or less perfect. They vary in size, from about the thirtieth to the thousandth of an inch in diameter.

Fig. 21.



At first the cells are all alike in shape and in texture; but they are greatly modified in both respects in

Fig. 22.



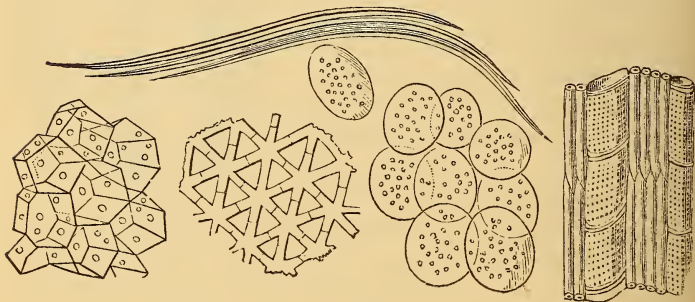
forming the varied tissues of the plant.

They may be lengthened out into tubes, as in the fibres of cotton, which are single cells thus drawn out. The soft, thin membrane which encloses them may become hard and thick, as in the shell of a walnut or the tough wood of an oak.

They may be closely crowded together, and nearly filled up with solid matter; or they may be loosely interlaced, and form vessels to contain the vegetable juices. Their contents are as varied as their structure, and, seen through the transparent walls, give rise to all the manifold colors of leaf and flower and fruit.

Figure 23 (from Wood's "Class-book of Botany") shows a few of the varied forms which cells assume. At the top we have wood-cells from the fibre of flax. Below

Fig. 23.



are represented the many-sided cells of the pith of elder; *stellate* (star-shaped) cells of the pith of the rush; spherical cells of the houseleek; and wood-cells of the oak.

147. *Organic Structure*.—This cellular structure is the characteristic of *organic* beings; that is, *plants* and

*animals*, as distinguished from *inorganic* things, or *minerals*; and hence it is called *organic* structure. The cell is "the simplest form of organic life," whether vegetable or animal. Cells are the *units* of which the most complicated organic tissues are made up. They are essentially different, then, from the particles into which an inorganic or mineral substance may be divided. Each of these particles has all the properties of the mass from which it was separated; and if we divide it into yet smaller particles, the same will be true of those; and so on indefinitely. But if we cut a cell in two, the halves do not have the properties of the whole; they are not smaller units, but the fragments of a unit.

148. *The Food of Plants*.—Plants get their food from the earth and the air, but much the greater part from the air. We know that there are plants which flourish in the most barren soil, or even upon the naked rock, and that some live and grow suspended in the air, and having no contact with the earth. Even those which demand a rich soil are indirectly indebted to the air for what they draw from the earth. The soil owes its fertility to the decomposition of organic matter; and this organic matter was originally produced by plants which had no rich soil to draw from, but were dependent mainly upon the air.

The atmosphere, then, is the storehouse from which plants directly or indirectly obtain nearly all their food. The portion which is purely of earthy origin is always insignificant, and often it is nothing at all. In fact, plants give to the earth far more than they get from it. This is illustrated by the accumulation of vegetable organic matter in the soil wherever vegetation is undisturbed from year to year. In uncultivated fields and in primeval forests we often find a great depth of rich mould. The more rank and luxuriant the vegetation, the more

rapidly this deposit increases, showing that the plants not only restore to the soil all that they have drawn from it, but are continually transferring fresh matter from the aerial storehouses to the earth.

But while the soil is enriched by undisturbed vegetation, it is impoverished by agriculture. The farmer carries away the crop from the field, with all that it has taken from both the earth and the air. The land cannot yield in this way year after year, unless he follows the example of nature, and restores to the soil an equivalent for what he removes. This he can do by the use of *manure*.

149. *The Earthy Portion of the Plant.*—If we burn wood or any other vegetable substance, almost all of it is dissipated into air. But a little ashes will remain; and these represent the earthy or *inorganic* portion of the plant. They consist mainly of alkaline chlorides, potash, soda, silica, metallic phosphates, calcic and magnesian carbonates, and ferric and manganic oxides. These are dissolved in the water which soaks through the soil and which is taken up by the roots of the plant. Much of the water is evaporated through the leaves, but the substances which it held in solution remain behind, and thus gradually accumulate in the tissues of the plant.

Since the plant must obtain from the soil the inorganic materials it needs, it is evident that it will flourish only in a soil containing those materials. This explains why certain plants thrive only in certain situations. A locality may be fertile for some species of vegetation and barren for others. The pines, which need little alkaline matter, will flourish in a sandy soil containing little alkali; but the maples and elms, which require a good deal of potash, cannot live in such a soil.

We have said that the farmer, who carries away the produce of the field with all that it has drawn from the

soil, must restore in the form of manure an equivalent for what he removes, or the field will soon become impoverished.

“A medium crop of wheat takes from one acre of ground about 12 pounds; a crop of beans, about 20 pounds; and a crop of beets, about 11 pounds of phosphoric acid, besides a very large quantity of potash and soda. It is obvious that such a process tends continually to exhaust arable land of the mineral substances useful to vegetation which it contains, and that a time must come, when, without supplies of such mineral matters, the land would become unproductive from their abstraction. . . . In the neighborhood of large and populous towns, for instance, where the interest of the farmer and market-gardener is to send the largest possible quantity of produce to market, consuming the least possible quantity on the spot, the want of saline principles in the soil would very soon be felt, were it not that for every wagon-load of greens and carrots, fruit and potatoes, corn and straw, that finds its way into the city, a wagon-load of dung, containing each and every one of these principles locked up in the several crops, is returned to the land, and proves enough, and often more than enough, to replace all that has been carried away from it.” — BOUSSINGAULT.

This renewal of fertility is sometimes attained by letting the field lie *fallow*, or uncultivated, for one or more years. The inorganic materials of the soil are mainly furnished by the gradual disintegration of the *rocks*; and while the field lies fallow this process is going on, under the influence of the oxygen and carbonic acid of the air, aided by the rains and changes of temperature. In this way, fresh portions of the rocks or of their ruins are rendered soluble and thus fitted for the nourishment of plants.

An *alternation of crops* may answer the same purpose as letting the field lie fallow. For instance, wheat and potatoes may be raised on the ground in alternate years. The wheat requires a large amount of silica and alkaline matter, while the potatoes take up no silica. The renewal of the soluble silica in the soil therefore goes on, while the potatoes are growing, as it would if the field were fallow.

Some soils abound in silicates so readily decomposed, that in every one or two years a sufficient supply for a crop of wheat becomes soluble. In Hungary there are large districts where wheat and tobacco have been raised alternately upon the same soil for centuries, the land never receiving back any of the mineral matter which is carried away with the crops. On the other hand, there are fields in which the amount of soluble silica required for a single crop of wheat is not separated from the insoluble masses in the soil in less than three or four years.

150. *The Organic Portion of the Plant.*—When we burnt the vegetable matter, much the greater part of it passed off into the air. This was the *organic* portion of the plant. It was taken from the air, and the burning has given it back in the very form in which the plant found it there.

We have learned that all the vegetable tissues, however varied in their texture and consistency, are almost entirely made up of the same kind of cells. The substance of which these cells are made is called *cellulose*, or *woody fibre*; and it is a compound of carbon, hydrogen, and oxygen,  $C_{12}H_{20}O_{10}$ . We have also learned that the plant contains small quantities of *albuminous* compounds (139), which, in addition to the elements just named, contain *nitrogen*. These four elements, then, are essential to the growth of the plant, and must be contained in its food.



151. *The Plant gets Hydrogen and Oxygen from Water.* — The hydrogen and the oxygen of the cellulose are obtained from the *water* which the plant takes in, not only through its roots, but through its leaves. It will be noticed that water contains hydrogen and oxygen in the same proportions as cellulose does.

152. *The Plant gets Carbon from Carbonic Acid.* — We have learned that carbon is a solid, and insoluble in water. Even if it were reduced to the finest powder and mixed with the water, it could not be taken up by the plant, since nothing but liquids and gases can pass through the walls of the cells. It must, then, be furnished to the plant in some liquid or gaseous compound, like the carbonic acid, which, as we have seen, is one of the gases mixed in the atmosphere.

Now if a leafy plant be placed under a glass vessel and set in the sunshine, and a stream of carbonic acid be made to pass slowly over it, it is found that a part of the carbonic acid is removed and replaced by oxygen. The plant absorbs the carbonic acid, decomposes it, retains the carbon, and exhales the oxygen.

We conclude, then, that it is from the carbonic acid in the atmosphere that plants get their carbon. In the leaves, under the influence of sunlight, the carbonic acid is decomposed, the carbon stored away in the plant, and the oxygen given back to the air.

Since carbonic acid is soluble in water, it is probable that plants also obtain a part of their carbon through the roots. Plants which live under water must get all their carbon from the gas dissolved in the water.

153. *The Plant gets Nitrogen from Ammonia.* — We have learned (123) that there is ammonia in the atmosphere, and (37) that this gas is very soluble in water. Hence it is washed out of the air by the rain, and, thus dissolved in water, is taken up by the roots of plants.

154. *The Growth of Plants is a Chemical Process carried on in the Leaf by the Sunlight.*—We have seen that the plant takes in water, carbonic acid, and ammonia; that it decomposes these substances; and that from their elements it elaborates all the organic compounds which enter into its own structure. The leaf is the laboratory in which this chemical process is conducted, and since it is only in sunshine or bright daylight that the work goes on, it is evident that the sunlight is the agency by which it is accomplished.

“The sun’s rays, acting on the green parts of the leaf, give to them the power of absorbing water, carbonic acid, and ammonia, and of constructing from the materials thus obtained the woody fibre, starch, sugar, and other compounds of which the plant consists. We have analyzed the woody fibre, and we know that it is composed of charcoal and water. Nineteen ounces of wood contain nine ounces of charcoal and ten ounces of water. Moreover, the amount of charcoal required to make nineteen ounces of wood is contained in thirty-three ounces of carbonic acid. If, then, we add together thirty-three ounces of carbonic acid and ten ounces of water, and subtract from this sum twenty-four ounces of oxygen, we shall have just the composition of wood. This is what the sun’s light accomplishes in the leaves of the plant. It decomposes the carbonic acid, and unites its carbon to the elements of water to form the wood.”—COOKE.

What is here stated to be true of wood is equally true of other vegetable products. If in their production carbonic acid and water alone take part, we have such substances as woody fibre, starch, sugar, and gum; and these make up nine-tenths of all vegetable structures. If the ammonia is likewise employed in the process, we have *nitrogenized* products, like albumen and caseine.

The force which the sunbeam exerts in the decomposi-

tion of carbonic acid in the leaf is very remarkable, since it overcomes the intense affinity of oxygen for carbon.

“In order to decompose carbonic acid in our laboratories, we are obliged to resort to the most powerful chemical agents, and to conduct the process in vessels composed of the most resisting materials, under all the violent manifestations of light and heat, and we then succeed in liberating the carbon only by shutting up the oxygen in a still stronger prison; but under the quiet influences of the sunbeam, and in that most delicate of all structures, a vegetable cell, the chains which unite together the two elements fall off, and, while the solid carbon is retained to build up the organic structure, the oxygen is allowed to return to its home in the atmosphere. There is not in the whole range of chemistry a process more wonderful than this. We return to it again and again, with ever increasing wonder and admiration, amazed at the apparent inefficiency of the means, and the stupendous magnitude of the result. When standing before a grand conflagration, witnessing the display of mighty energies there in action, and seeing the elements rushing into combination with a force which no human agency can withstand, does it seem as if any power could undo that work of destruction, and rebuild those beams and rafters which are disappearing in the flames? Yet in a few years they will be rebuilt. This mighty force will be overcome; not, however, as we might expect, amidst the convulsion of nature, or the clashing of the elements, but silently, in a delicate leaf waving in the sunshine.” — COOKE.

155. *Plants purify the Air for the Respiration of Animals.* — We have learned (144) that by the various forms of combustion going on in nature, eight thousand millions of pounds of oxygen are daily removed from the atmosphere; and that an immense amount of carbonic

acid is pouring back into the air as one of the chief products of this combustion. The atmosphere, then, is continually losing the element which is essential to the support of animal life, and receiving in its place a gas which, even when largely diluted with air, is a deadly poison to animals.

But we have also learned that during the daytime plants are constantly drinking in this carbonic acid, and giving out an equal bulk of pure oxygen. They are thus purifying the air for the respiration of animals. They breathe in what animals breathe out, and breathe out what animals breathe in; so that the air is kept in a fit state to sustain both forms of organic life.

An Oriental fable narrates that a nightingale and a rose-tree were once imprisoned in a cage of glass, and long lived together there, happy in each other's society. But at last the rose-tree withered and died; and the bird soon pined away, and perished with grief at the loss of its beloved companion. The fancy of the poet is in perfect harmony with the facts of science, and prettily illustrates the dependence of animals upon plants for the very breath of life.

156. *Plants prepare Food for Animals.*—We have seen that the plant draws its food directly from the earth and the air. It has the power of forming organic compounds out of inorganic matter. The animal, on the other hand, has no such power. It can elaborate its tissues only from organic matter, which it receives ready-made from the vegetable kingdom. It may get this matter either directly from the plant, as when it eats vegetable food, or, indirectly, as when it eats animal food; but in either case the origin is the same. By the process of digestion the organic compounds originally prepared by the plant are converted into bones, muscles, nerves, or whatever else enters into the struc-

ture of the animal. In this process they do not undergo any radical change, but merely "become parts of more finely organized tissues." We find in the blood albumen and caseine, having precisely the same composition as when prepared from potatoes, and the substance of the muscles does not differ essentially from the gluten of wheat-flour.

157. *The Relations of Plants and Animals to each other and to the Air.* — The plant, then, is a *producer* of organic materials; the animal, a *consumer* of these materials. "While the plant is a true apparatus of reduction, the animal is a true apparatus of combustion, in which the substances it derived from the vegetable are burnt, and restored to the atmosphere in the form of carbonic acid, water, and ammonia, ready to be again absorbed by the plant and to repass through the phases of organic life. Our bodies are furnaces, — furnaces continually burning, — whose fuel is our own flesh, and the smoke of whose fires is the food of the plant. . . .

"When the foundations of the globe were laid, there were collected in the atmosphere all the essential elements of organized beings. From this inexhaustible storehouse the plant absorbs water, carbonic acid, and ammonia, which were placed there for its use, and which have been made to serve as its nourishment and food. It is the special office of the plant to elaborate from these few mineral substances, and a small amount of earthy salts, all the materials of organized beings. The animal receives these crude materials already prepared, and builds with them its various tissues; but no sooner are the cell-walls finished, and the structure ready to discharge its vital functions, than it is consumed by almost the very act which gave it life. The carbonic acid, water, and ammonia are restored to the atmosphere, and the cycle is complete." — COOKE.

## NATURAL VEGETABLE PRODUCTS.

158. *Starch*. — *Starch* has already been mentioned as one of the most important products of vegetable growth. Its chemical composition is precisely the same as that of woody fibre,  $C_{12}H_{20}O_{10}$ . It consists of round or oval granules, varying considerably in size in different vegetables. The largest are about  $\frac{1}{260}$ th, and the smallest less than  $\frac{1}{3000}$ th of an inch in diameter. In the potato (Figure 24) they are considerably larger than in wheat-

Fig. 24.



Fig. 25.



flour (Figure 25). These granules consist of concentric layers, formed one after another, about a *nucleus* or centre. Lines, indicating these layers, can sometimes be seen on the surface of the larger grains, as in those of potato starch in the figure. Since the grains from the same kind of plant are tolerably uniform in size and shape, while they vary much in different species, the microscope will show to what plant starch-grains belong. Adulterations of arrowroot, and of other starchy substances, may thus be detected.

Starch is heavier than water, and is insoluble in cold water, alcohol, or ether. If, however, it be placed in water at  $150^{\circ}$ , the grains swell up and burst, forming a paste or jelly. When long boiled in water, starch is converted into the soluble *dextrine* (162).

The test for starch is iodine, with which it forms a compound of a deep blue color (60). Bromine gives starch a brilliant orange tint.

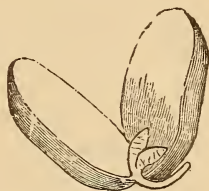


Starch is the form in which food is stored up in the plant for future use. In the seed, it furnishes the material for the growth of the embryo, before it can draw its nourishment from the earth and the air. It sometimes surrounds the embryo, as in the seed of the onion (Figure 26); and sometimes it is found in the *cotyledons*, or *seed-leaves*, of the embryo itself, as in the seed of the bean (Figure 27). When the seed germinates, the starch is dissolved, and converted into dextrine, and this into sugar, which is even more soluble. It is then dissolved in the sap, which conveys it wherever it is needed for the growth of the infant plant.

Fig. 26.



Fig. 27.



Several forms of starch are extensively used as articles of food. *Arrowroot* is obtained from the roots of a tropical plant, which is cultivated in the West Indies, especially in Bermuda and Jamaica, and to some extent in the East Indies and in Africa. *Tapioca* is also made from the roots of plants which grow in the West Indies, South America, and Africa. *Sago* is extracted from the pith of several species of palm-tree, in India and the islands of the Indian Archipelago. *Corn-starch*, *maizena*, and *farina*, and various other preparations of the kind, are made from the starch of Indian corn, wheat, etc. Potatoes yield from 12 to 27 per cent of starch; peas and beans from 33 to 36 per cent; wheat-flour, 56 to 72 per cent; rye-meal, 61 per cent; maize, 81 per cent; rice, 83 to 85 per cent.

Starch is also used in large quantities for laundry purposes; in the manufacture of cotton cloth, as a *sizing* for the thread; and in the making of dextrine and grape-sugar (161, 162).

159. *Sugar*. — Sugar, like starch, is a vegetable product, prepared for the future growth of the plant. It is found, dissolved, in varying proportions, in the juices of all plants. In ripe fruits it is quite abundant; pears containing 6 per cent; peaches,  $16\frac{1}{2}$  per cent; and cherries, 18 per cent. In rye-meal there is about  $3\frac{1}{2}$  per cent of sugar; in wheat-flour, from 4 to 8 per cent; in beet-root, from 5 to 8 per cent; and in dried figs, more than 60 per cent.

There are many kinds of sugar, of which the two most important are *cane-sugar* and *grape-sugar*.

160. *Cane-Sugar*. — Cane-sugar,  $C_{12}H_{22}O_{11}$ , is found in the juices of many plants. It is mostly prepared from the juice of the *sugar-cane*; but on the Continent of Europe, it is largely made from *beet-juice*. In tropical regions, it is also manufactured from the juice of the *date-palm*; and in the Northern United States it is obtained in considerable quantities from the sap of the *rock* or *sugar maple*.

In the manufacture of sugar from sugar-cane, the juice is first extracted from the canes by pressure, then mixed with a small quantity of slaked lime, and heated nearly to boiling. The lime serves to neutralize the acid in the juice, and also to remove the albuminous matter, which, if left in the sugar, would soon cause it to ferment and spoil. The juice is next evaporated in open pans to a thick syrup, which is allowed to cool and crystallize, and is then drained in perforated casks. The liquid drained off is known as *molasses*.

By this process, *raw* or *brown sugar* is obtained. This is *refined* by dissolving it in water, adding albumen (usually from ox-blood), and heating it. The albumen separates most of the impurities from the solution, which is then filtered through bone-black to remove the coloring matter. It is then boiled down in *vacuum pans*, large

vessels from which the air is partially exhausted by pumps, in order that the evaporation may be carried on at a lower temperature than in open pans. By this process there is a saving of fuel, while the quantity of sugar obtained is increased. The concentrated syrup is crystallized in conical moulds, with an opening at the bottom for drainage, and thus becomes *loaf-sugar*.

When sugar crystallizes very slowly, it forms the large and very hard crystals seen in *rock-candy*. In making loaf-sugar, the syrup is frequently stirred, to prevent the formation of these large crystals.

If cane-sugar be heated to about  $400^{\circ}$ , it loses two atoms of water, and is converted into *caramel*, a dark brown substance, much used for coloring brandy and other spirits.

The manufacture of sugar from the sugar-cane, and other sources, is now one of the largest branches of human industry, but its importance is of comparatively modern date. Sugar was known to the Greeks and Romans only as a medicine or a curiosity. For several centuries after the Augustan age, we find scarcely any mention of it; and, even so late as the seventh century, Paul of Ægina describes it as "India salt, resembling common salt in color and consistency, but honey in taste and flavor." The sugar-cane appears to have been introduced into Europe by the Saracens, who cultivated it in Rhodes, Cyprus, Crete, and Sicily, in the ninth century. In the fifteenth century, it was transplanted into Madeira and the Canary Isles, whence it was probably brought to America. It became known in England in the fourteenth century; and, in 1329, it was sold in Scotland at one ounce of silver (equal to four dollars of our money) a pound. It did not become an article of ordinary consumption until the beginning of the seventeenth century. Since that time its use has very rapidly increased, and it

seems destined to an indefinite extension. "It is so nutritious, wholesome, and agreeable, that there never can be a limit to its use, except in a prohibition or an inability to buy it. Men and nations differ widely in respect to most kinds of food, sauce, and drinks. Neither wheat, rice, flesh, nor potatoes can command unanimous favor. No article of housekeeping, save sugar, can be named, which is so universally acceptable to the infant and the aged, the civilized and the savage."

The annual production of sugar throughout the world is estimated at more than 5,000 millions of pounds, of which nearly 88 per cent is cane-sugar; about 7 per cent, beet-sugar; 4 per cent, palm-sugar; and about 1 per cent, maple-sugar. According to Chambers's Encyclopædia (1867), the yearly consumption *for each inhabitant*, in several great countries, is as follows: Russia,  $1\frac{1}{2}$  lbs.; Austria,  $1\frac{1}{2}$  lbs.; France, 4 lbs.; Belgium, 6 lbs.; Great Britain, 30 lbs.; United States, 40 lbs.

161. *Grape-Sugar*.—Grape-sugar, or *glycose* (less properly spelled *glucose*),  $C_{12}H_{24}O_{12}$ , is found in the juice of grapes, plums, cherries, figs, and many other fruits, and may often be seen in a crystalline form on raisins and dried figs. It likewise occurs in honey.

It is manufactured on a large scale, in Europe, from starch. A mixture of starch and water, at a temperature of about  $130^{\circ}$ , is made to flow gradually into a vat, containing boiling water, acidulated with one per cent of sulphuric acid. In about half an hour, the starch is converted into sugar. The sulphuric acid is neutralized with chalk, forming a deposit of calcic sulphate; and the clear solution of sugar is then boiled down and crystallized. Instead of starch, in this process, paper, flax, cotton and linen rags, sawdust, or any other form of woody fibre, may be used. The woody fibre is first converted into starch, and then into sugar.

Glycose is largely used in Europe for confectionery, for adulterating cane-sugar, and for the manufacture of beer and spirits.

162. *Dextrine*.—Dextrine, or *British gum*,  $C_{12}H_{20}O_{10}$ , is obtained by heating starch to about  $400^{\circ}$ ; or by subjecting the starch to the long-continued action of dilute acids, at a high temperature. It is often used instead of gum-arabic in calico-printing, and for stiffening certain goods. It is also applied to the back of postage-stamps and other adhesive labels.

When wheaten bread is baked, a small quantity of starch is converted into dextrine on the outside of the crust, forming a brownish glazing.

163. *Cellulose and Gun-Cotton*.—*Cellulose*, or *woody fibre*,  $C_{12}H_{20}O_{10}$ , has already been described (150). It is insoluble in water, alcohol, or ether, but dissolves in an ammoniacal solution of cupric oxide (oxide of copper).

*Gun-cotton*, or *nitro-cellulose*, is made by the action of strong nitric acid upon cellulose. Cotton wool is immersed, in small portions at a time, in a mixture of equal volumes of strong nitric and sulphuric acids. It does not undergo any apparent change; but, on being washed and dried, it is found to be very inflammable. Six atoms of its hydrogen have been replaced by  $NO_2$ , so that its composition is now represented by  $C_{12}H_{14}(NO_2)_6O_{10}$ .

The use of gun-cotton, as a substitute for gunpowder, has been proposed, for the following reasons:—

(1) The explosive force of gun-cotton is, weight for weight, greater than that of gunpowder. (2) The products of the combustion of gun-cotton, being chiefly carbonic acid and nitrogen, are not so apt to foul the gun. (3) When moistened, it becomes inexplusive, and only requires drying to render it again explosive.

The reasons which render the general adoption of this substance doubtful are,—(1) its liability to explode on

percussion; (2) the possibility of its spontaneous decomposition when kept for a length of time.

A variety of gun-cotton, containing a smaller proportion of  $\text{NO}_2$ , dissolves readily in a mixture of ether and alcohol, and yields a solution termed *collodion*. This is largely used for the purpose of forming a thin coating on glass to receive silver salts, upon which the photographic image is formed.

164. *Vegetable Parchment*.—When paper is immersed for a short time in a mixture of two volumes of oil of vitriol and one of water, and thoroughly cleansed by repeated washings with water, and finally with ammonia, it is changed into a substance resembling parchment, and often called *vegetable parchment*.

“The alteration which takes place in the paper is of a very remarkable kind. No chemical change is effected, nor is the weight increased; but it appears that a molecular change takes place, and the material is placed in a transition state between the cellulose of woody fibre and dextrine.”

Vegetable parchment is now extensively used instead of parchment for legal and other documents. In some respects it is preferable to the old kind, for insects attack it less.

165. *Vegetable Acids*.—The acids of vegetable origin are almost innumerable. We shall describe here only a few of the most important.

*Tartaric acid*,  $\text{C}_4\text{H}_6\text{O}_6$ , is found, either free or combined with potash or lime, in tamarinds, grapes, pineapples, and many other vegetables. It is usually seen in the form of colorless crystals, which have an agreeable acid taste, and are soluble in water and alcohol. It is used in large quantities in calico printing and dyeing, and also in medicine, especially for making effervescent draughts. Some of its more important compounds are



the familiar substances, *Rochelle salts*, *cream of tartar*, and *tartar-emetic*.

*Citric acid*,  $C_6H_8O_7$ , is usually prepared from lemons. It is also contained in gooseberries, currants, raspberries, strawberries, and other fruits. It is a crystalline solid, readily soluble in water, and has an intensely sour taste. It is used in silk-dyeing, in calico-printing, and in medicine.

*Malic acid*,  $C_4H_6O_5$ , is one of the most abundant of these vegetable acids. It is found in apples, from which (Latin, *malum*) it takes its name; in currants, barberries, rhubarb, and many other fruits and plants. It forms needle-shaped crystals, which are very soluble in water and alcohol. It is not used in the arts or in medicine.

*Oxalic anhydride*,  $C_2O_3$ , is not known in a free state. It is found in the juice of wood-sorrel (*oxalis acetosella*, from which it takes its name), and of many other plants, in combination with potash or lime. It forms a compound with water,  $H_2C_2O_4$ , which is *oxalic acid*. This is a crystalline substance, and is very poisonous. It is much used in cotton-printing and straw-bleaching, and is prepared in very large quantities by the action of caustic potash on sawdust. Crude potassic oxalate (oxalate of potash) is thus formed, which, by means of lime, is converted into the insoluble calcic oxalate (oxalate of lime), and this is decomposed by sulphuric acid.

*Tannic acid* and *tannin* are the names given by chemists to a number of compounds of C, H, and O, which are characterized by a well-marked *astringent* taste. They are soluble in water and alcohol, and form precipitates with most metallic oxides. Ferric salts yield black, or nearly black, precipitates, which are the basis of the ordinary writing *inks*. Tannic acid also precipitates *gelatine* (or *glue*); and it is by a similar process that it converts the gelatinous tissue of raw hides into *tanned*

leather. The bark and leaves of most forest trees, such as the oak, elm, willow, horse-chestnut, and pine, and of many fruit-trees, as the pear and plum, contain considerable quantities of tannin. Coffee and tea likewise contain modifications of this compound; but the tannin in coffee, unlike that from all the other plants we have named, does not form the black salt with iron. A drop of tea on a knife-blade becomes inky at once, but a drop of coffee does not.

166. *Natural Fats and Oils*.—The natural oils and fats (fats being merely solid or semi-solid oils) are all compounds of organic acids, called the *fatty acids*, with a base called *glycerine* (167), and they are found in both plants and animals. *Cocoa-nut oil*, *palm oil*, and *nutmeg butter* are examples of vegetable fats.

The vegetable *oils* are divided into the *fixed oils*, which cannot be distilled without decomposition, and the *volatile oils*, which bear distillation without change. The *fixed* oils are divided into *drying* and *non-drying oils*. The former become dry and solid from oxidation, when spread out thin and exposed to the air; while the latter remain unaltered. The chief drying oils are those of linseed, hemp, poppy, and walnut, all much used in paints and varnishes; and the most important non-drying oils are olive oil, almond oil, and colza oil, which are extensively used in making soap, candles, and illuminating oils, in wool-dressing, and for many other purposes. Castor oil seems to form a connecting link between these two classes of oils, as it gradually becomes hard by long exposure to the air.

The *volatile* or *essential* oils are believed to constitute the odorous principles of plants. Most of them are nearly colorless when fresh, but darken on exposure to light and air. When long exposed to the air, they absorb oxygen, and become *resins*. They are largely used in the manu-

facture of perfumery; for flavoring confectionery and liquors, and for various other purposes in the arts; and in medicine.

167. *Soap*. — When the oils or fats are boiled with an alkali, they undergo the remarkable change called *saponification*. The fat is decomposed into a *fatty acid* and *glycerine* (166). The acid combines with the alkali to form *soap*, and the glycerine passes into solution. If the alkali be *soda*, a *hard* soap is formed; if *potash*, a *soft* soap. The soaps, then, like the fats, are true *salts*.

Fats may also be separated into acid and glycerine by distillation with steam, at a temperature between 500° and 600°.

Glycerine ( $C_6H_{16}O_6$ ), is a colorless viscid liquid, of a sweet taste (whence its name, which is from a Greek word, meaning *sweet*), soluble in water and alcohol, but nearly insoluble in ether. It is used in medicine, in making copying-ink, and as a lubricating agent.

The most important of the fatty acids are *oleic*, *stearic*, and *palmic*, or *palmitic*. They are used on a large scale in the manufacture of candles.

168. *Wax*. — The various forms of vegetable wax resemble in many respects the fixed oils, but are quite different from them in chemical composition. They are solid or semi-solid substances; easily broken when cold, but soft and pliable when moderately warm, and melting below 212°. They are insoluble in water and cold alcohol, but dissolve readily in ether; they burn with a bright flame, and are not volatile. They are found as exudations on leaves and fruits, where they form the *glaucous* surface, which repels water. Some fruits, as the bayberry, are thickly coated with wax.

169. *Gums and Resins*. — In the strict sense, a *gum* is a substance which dissolves in water, forming a mucilage; but is insoluble in ether, alcohol, and oils. A *resin*,

on the other hand, is insoluble in water, and soluble in ether, alcohol, and oils. *Gum arabic* and *gum senegal* are products of different species of *acacia*, and are extensively used in the arts. *Gum tragacanth* is the product of a shrub which grows in Persia and Asia Minor. It is only partially soluble in water, forming a white paste instead of a mucilage. It is used for paste and cement, and also for stiffening woven fabrics. Dextrine is now much used as a substitute for these and other gums (162).

The *resins* are divided into the *hard resins*, the *soft resins*, and the *gum-resins*. The *hard resins* are brittle at ordinary temperatures, and are easily pulverized. The most important are *copal*, the varieties of *lac*, *mastic*, and *sandarach*. They are much used for varnishes and for other purposes in the arts. The *soft resins* are easily moulded by the hand, and some of them are semi-fluid, in which case they are called *balsams*. They consist essentially of hard resins dissolved in oils. On exposure to the air, they are oxidized and converted into hard resins. Under this head are placed *turpentine*, *Canada balsam*, etc. The *gum-resins* are the milky juices of certain plants, solidified by exposure to the air. They consist of a mixture of gums, resins, and essential oils. *Caoutchouc*, or *india rubber*, is the most important of the gum-resins. It is obtained from several quite different kinds of trees. The original *india rubber* of the East Indies is the product of a species of fig-tree. *Gutta-percha* is the dried milky juice of a tree found in Malacca and the neighboring islands. The applications of these two gum-resins in the arts are almost innumerable, and are continually increasing. Many valuable medicines are obtained from gums and resins. *Amber* is a *fossil* resin.

170. *Vegetable Alkaloids*.—A great variety of alkaline compounds, known as *alkaloids*, are produced by plants. They are mostly formed in the bark and in the

leaves. Among them are some of the most active poisons and some of the most valuable medicines, as *morphine*, *strychnine*, and *quinine*. Tea and coffee owe their peculiar effects to the same alkaloid, *theine*. *Opium* is remarkable for the great number of these compounds which it contains. The narcotic power of *tobacco* is due to a highly poisonous alkaloid called *nicotine*.

171. *Proteine Bodies*. — Under the term *proteine bodies* have been included the most important *nitrogenized* products of plants, as *albumen*, *caseine*, and *fibrine*. They all have essentially the same composition, containing about 53.6 per cent of carbon, 7.1 of hydrogen, 15.6 of nitrogen, 22.1 of oxygen, and a varying quantity of sulphur not exceeding 1.6 per cent. They are found in animals as well as in plants, and there are several similar compounds found only in animals.

The *proteine bodies* form the most essential articles of food for animals, since, as we have learned, *nitrogenized* compounds are indispensable to the repair of the machinery of the body. And for these, as for all other constituents of their food, animals are directly or indirectly dependent on plants.

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## SUMMARY.

The atmosphere contains oxygen, nitrogen, carbonic acid, and watery vapor, with traces of ammonia and nitric anhydride.

Ordinary combustion, decay, and respiration are chemical processes, differing from one another mainly in the rapidity and the completeness with which they take place.

The division of substances into *combustibles* and *supporters of combustion* is convenient, though merely con-

ventional; since combustion consists in the chemical union of two or more elements, and, in reality, one of the elements is just as combustible as another.

The present materials of the earth, being mainly compounds of hydrogen and carbon with oxygen, and of the metals with oxygen, chlorine, and sulphur, must be regarded as products of combustion.

The *rusting* of the metals is a process of slow combustion.

The products of combustion, decay, and respiration are chiefly *carbonic acid*, *water*, and *ammonia*.

The growth of plants is a chemical process, carried on in the leaf by the agency of the sunbeam. In growing, plants remove from the air carbonic acid, water, and ammonia. These compounds are broken up; the oxygen in part given back to the air; and the other elements, with the remaining oxygen, re-arranged so as to form the various vegetable compounds.

By removing the products of combustion, and restoring oxygen, plants purify the air for the respiration of animals.

Animals derive all their food, directly or indirectly, from plants; while plants derive their food, directly or indirectly, from the air.

Most of the natural vegetable products are compounds of carbon, hydrogen, and oxygen; but some contain nitrogen in addition to these, and are, therefore, called *nitrogenized* compounds. Of the former class, the most important are starch, sugar, dextrine, the vegetable acids, the fats and oils, wax, the gums and resins, and the vegetable alkaloids; of the latter class, the proteine bodies, including albumen, caseine, and fibrine. The latter are the most essential articles of food for animals, since the nitrogenized products make up almost the entire bulk of the animal structure.



## DESTRUCTIVE DISTILLATION AND ITS PRODUCTS.

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172. When vegetable substances are heated in closed vessels, so as to exclude the oxygen of the air, they are broken up into a number of compounds, which vary with the temperature to which they have been exposed. When vegetable matter burns or decays, these organic compounds, as we have seen, are broken up by the affinity of oxygen brought to bear upon them from without; while in the other case they are broken up by the internal action of heat. In the first case, new compounds are formed by the addition of new material; in the second case, by subdivision, without any addition of new material. The first process is called *combustion*; the second, *destructive distillation*.

173. *The Preparation of Charcoal.*—We have a very simple case of destructive distillation in the preparation of charcoal. This process may be illustrated by putting pieces of dry wood into a flask, closed with a cork, through which a glass tube passes. This tube passes into a cold glass bottle, and thence to a jar over water. Heat the flask, and the wood turns black. The jar fills with an inflammable gas. Hold a cold glass vessel over the flame of this gas, and moisture collects upon it, showing that water is a product of the burning of this gas. Carbonic acid also is found to be produced. This gas obtained from the wood must,

therefore, be a compound of hydrogen and carbon. A part of the carbon of the wood combines with hydrogen, to form the inflammable gas; while the greater part remains behind as a black solid. This black residue is charcoal, a form of carbon. If the heating is continued, a liquid product is also obtained.

One way of preparing charcoal is to place billets of wood in an iron cylinder, which is closed air-tight and heated to dull redness. The volatile products are driven off and allowed to escape through a flue, and the solid charcoal remains behind.

A ruder method is practised in the country, where wood is plenty. A stake is set in level ground, and brushwood heaped about its base. Wood is then stacked round the stake, so as to form a mound some 20 or 30 feet in diameter. This mound is then covered, first with leaves or turf, and then with earth, leaving only a small opening at the bottom, through which the wood is set on fire. When the fire is well under way, the mound is covered more deeply and allowed to burn slowly out. This requires about a month. The burning of a part of the wood furnishes heat for charring the rest.

174. *The Products of the Distillation of Wood.*—When hard wood, as beech, is subjected to destructive distillation in a retort, and the volatile products are condensed in a suitable vessel, four principal classes of substances are formed: (1) gases; (2) a watery fluid; (3) a dark resinous fluid; (4) charcoal.

(1) This product is a mixture of inflammable gases, the most important of which are the two *hydrocarbons* (or compounds of hydrogen and carbon), *marsh-gas*,  $H_4C$ , and *olefiant gas*,  $H_4C_2$ .

(2) This product is an acrid liquid, known as *pyro-ligneous acid*, or *wood vinegar*, which is used in the manufacture of *acetic acid*.

(3) This product is *wood tar*, a thick liquid, insoluble in water, but soluble in alcohol. Its chief use formerly was for tarring and calking ships, but recently it has become an important source of illuminating and lubricating oils. These oils will be described hereafter.

(4) This product is the charcoal remaining in the retort. It is used chiefly as fuel and in reducing metallic ores.

175. *Ingredients of Wood Tar.*—When beech-wood tar is distilled, a light oil passes over first, called *eupion*, or *wood naphtha*. It is now often sold under the name of *benzole*, and used as a burning-fluid, for removing oil-stains from clothes, and for countless other purposes. It burns with a brilliant white flame, free from smoke; but its extreme inflammability makes it a dangerous liquid for lamps.

After this light oil has distilled over, a heavy oil follows. It contains various ingredients, the chief of which are *creosote* and *paraffine*.

176. *Creosote.*—This is an oily, colorless liquid, with a peculiar smoky odor. It has remarkable *antiseptic* (or preservative) properties. A piece of flesh steeped in a very dilute solution of it dries up into a mummy-like substance, which refuses to decay. Meat, as tongues or hams, may be almost instantly *cured* by dipping it into a solution containing one part of creosote to 100 parts of water or brine. It is this substance which imparts to wood-smoke its property of preserving meat. It is a compound of carbon, hydrogen, and oxygen.

177. *Paraffine.*—This is a pearly-white, tasteless, and odorless solid. The most corrosive acids and alkalies have no effect upon it. Hence its name, from *parum*, little, and *affinis*, from which *affinity* is derived.

It burns with a bright white flame, without smoke. It is now much employed as a material for candles, which

for purity and lustre are not surpassed by even the best wax candles.

Unsized paper, after having been soaked in paraffine, may be kept for weeks in concentrated sulphuric acid without undergoing the slightest alteration. Hence it is an excellent coating for the labels of bottles in which acids are kept.

178. *Asphalt*.—Asphalt, or pitch, is the residue left after distilling tar. It is used for varnishes, and as a material for making lamp-black.

179. *Slow Destructive Distillation*.—When vegetable substances decay with a partial or complete exclusion of air, we have a kind of *slow* destructive distillation. Hydrocarbon gases, which in some places escape from the earth in large quantities, are one of the products of this process; the well-known coal-oils are another; and coal is a third. The gas obtained by stirring the mud in marshes and at the bottom of stagnant pools is formed in this way, and is made up chiefly of marsh-gas,  $H_4C$ , and carbonic acid,  $CO_2$ .

180. *The Formation of Mineral Coal*.—In tropical swamps where vegetation is rank, vast masses of vegetable matter accumulate, and gradually decay under water. In some cases the land at the bottom of these swamps is slowly sinking; and the bed of peat, as it sinks with it, becomes covered with mud and sand, which numerous streams are washing down upon it. This goes on, year after year and century after century, until the bed is buried hundreds of feet beneath the surface. The vegetable matter, thus sunk in the earth and subjected to enormous pressure, gradually undergoes a process of internal combustion similar to that which takes place under water. In many cases the decomposition is hastened by the agency of the internal heat of the earth. It is probable that the vast beds of coal found in various parts of

the earth have been thus formed. All this coal is the remains of an ancient vegetation, and it undoubtedly required millions upon millions of years to complete its conversion into coal.

181. *Hard and Soft Coals.*—The mineral coals may be conveniently divided into *hard*, or *anthracite*, and *soft*, or *bituminous* coal, and there are several varieties of each.

The main differences between the two are these: hard coal is almost pure carbon, while soft coal contains also considerable hydrogen and some oxygen; hard coal still retains the cellular structure of the wood, which is clearly seen under the microscope, while in soft coal this cellular structure is almost entirely wanting; hard coal burns without flame, soft coal with flame.

182. *Products of the Distillation of Bituminous Coal.*—The products obtained by the destructive distillation of coal are still more numerous than those obtained from wood. Wood, containing much oxygen and comparatively little nitrogen, furnishes compounds which contain much acetic acid and little ammonia, and which, therefore, have an *acid* reaction. Coal, on the other hand, contains much nitrogen and little oxygen, and gives products rich in ammonia, and having consequently an *alkaline* reaction.

When coal is distilled at high temperatures, an abundance of an inflammable gas is obtained, and also a large amount of liquid products, which are then called *tars*.

When coal is distilled at a low temperature, little gas is obtained, and the liquid products are then called *oils*.

183. *The Composition of Coal-tar.*—Coal-tar has been found to contain three classes of substances:—

- (1) Acid oils.
- (2) Alkaline oils.
- (3) Neutral oils.

(1) The most important and abundant ingredient of the acid oils is *carbolic acid*,  $C_6H_6O$ . It is analogous to creosote, and has even more powerful antiseptic properties. It is one of the most valuable *disinfectants* known, and both the acid and the compound which it forms with lime are now much used for this purpose. It is also largely employed in dyeing silk and woollen goods. The dye-stuff is prepared by heating carbolic acid moderately with nitric acid, and is called *picric acid*. On evaporating this liquid, yellow scaly crystals are obtained. Like all the tar colors, its dyeing qualities, when in solution, are most intense. Silk and woollen goods put into the solution, even when cold, assume a rich yellow color, far surpassing that of other dyes.

(2) The alkaline oils constitute but a small fraction of the tar. Their most important ingredients are ammonia and *aniline*,  $C_6H_7N$ .

Aniline is an oily substance which, when acted upon by compounds which readily part with oxygen, furnishes a complete series of the most brilliant dyes. The preparation of these rich dyes from aniline is one of the most interesting discoveries of modern times, and has caused almost a revolution in the arts of dyeing and calico-printing. It is still more surprising when we consider that these brilliant colors are obtained from what was until recently a disagreeable waste product of the gas-works. When first prepared, they were worth their weight in gold; now, they can be bought at a comparatively moderate price.

Their dyeing qualities are so intense, that a little material goes a great way; so that, notwithstanding their high price, they are more economical than other dyes.

(3) The neutral oils are the *coal-oils* proper. They contain a great variety of compounds, both liquid and solid, the latter being held in solution. Of the liquids,



*benzole*, *toluole*, and *cumole* are the most important; and of the solids, *paraffine* and *naphthaline*.

184. *Benzole and Nitro-benzole*.—Benzole is a very important compound, as it is the material from which aniline is usually prepared. The symbol for benzole is  $C_6H_6$ . When mixed with concentrated nitric acid, it loses one atom of H, and takes one of  $NO_2$  in its place, and becomes *nitro-benzole*,  $C_6H_5NO_2$ .

Nitro-benzole is the artificial *oil of bitter almonds*, and is much used in the art of perfumery. Its most important use, however, is in the preparation of aniline. When heated with acetic acid ( $C_2H_4O_2$ ) and iron filings, it loses two atoms of oxygen and takes up two of hydrogen, and is converted into aniline,  $C_6H_7N$ .

185. *Toluole and Cumole*.—Toluole,  $C_7H_8$ , and cumole,  $C_9H_{12}$ , are the chief ingredients of the well-known illuminating or lamp oils obtained from coal.

186. *Naphthaline*.—Naphthaline is a beautiful, pearly-white solid. It is inflammable, but burns with a smoky flame and a disagreeable odor. Brilliant red and blue colors, rivalling those prepared from aniline, have lately been obtained from this solid.

When vegetable matter is distilled at a high temperature, benzole and naphthaline are formed in great abundance, with but small quantities of toluole, cumole, and paraffine. When, on the other hand, the distillation is conducted at a low temperature, toluole, cumole, and paraffine are formed in large quantities, with but little benzole and naphthaline.

## COAL-OILS.

187. At the beginning of the present century, the means of lighting our dwellings consisted, in the main, of poor tallow candles and dim and dirty oil-lamps. On

the continent of Europe, whale-oil and other animal oils were costly, and resort was had to natural tar and bituminous slate, in order to obtain illuminating oils. For more than twenty years past, lamp-oils have there been extensively prepared from wood, rosin, and bituminous matter.

In Great Britain and in this country the manufacture of coal-oils is of much more recent growth, because the extensive whale-fisheries supplied all the wants of the market.

The manufacture of coal-oil was introduced into this country in 1853, and was at first confined to those districts where bituminous coal could be mined at a cheap rate.

Soon after this manufacture was established in this country, and after the value of coal-oils came to be fully recognized, attention was drawn to *petroleum*, or rock-oil, as a ready means of supplying these oils cheaply. On examination, this oil was found to be analogous, in its composition and its properties, to that obtained by the destructive distillation of soft coal and other bituminous substances.

188. *The Origin of Petroleum.*—All scientific men are agreed that the petroleum found in the earth results from the decomposition of organic matter, and nearly all are agreed that it results mainly from the decomposition of *vegetable* matter. It is, however, a disputed point, whether it results from the original decomposition of the vegetable substances, or from the action of the internal heat of the earth on the bituminous coal at a subsequent period.

It is probable that the petroleum now found in the earth is the product both of the original decomposition and of subsequent distillation. Petroleum is, however, rarely found in contact with bituminous strata of any

kind. It is more often found in fissures in sand rocks ; rocks in which no oil could ever have been generated, since whatever organic matter they might have contained was too much exposed to atmospheric oxygen to admit of its being *bitumenized*, or made bituminous. It is not only impossible that the oil could have originated in these sand rocks, or in the sandy shales which underlie them in the oil region in Western Pennsylvania ; but it is most probable that the oil ascended from still lower rocks in the form of vapor, which condensed in the cavities above. Since, then, petroleum is seldom found where it originated, but, ordinarily, in cavities of rocks higher up, it seems probable that it is *mainly* the product of distillation.

The chemical conditions essential to the generation of oil have evidently existed over a very wide area ; but the oil is found only where fissures exist in the rocks. These fissures serve two purposes : one, to give space for the formation and expansion of the hydrocarbon vapor ; the other, to furnish receptacles for the condensed oils. These fissures must connect with the sources of the oil. If they have any outlets at the surface of the earth, by which the more volatile portions of the oil may escape as gas, the oil within them becomes thicker and heavier. Hence, as a general rule, the oil found near the surface is heavy, the cavities containing it being likely to have outlets. It may, of course, happen that a deeply-seated fissure has such an outlet.

189. *How Petroleum is obtained.*—The oil is obtained by piercing one of these cavities by a well. It often happens that the upper part of the cavity is filled with pent-up uncondensable gases. In this case, if the well happens to pierce the lower part of the cavity, the expansive force of the confined gases will drive the oil from the well in a continuous stream. Oil is often forced

from a new well with such velocity, that it rises in a jet a hundred feet high.

It sometimes happens that the lower part of the cavity is filled with brine, upon which the oil floats. If, in this case, the well pierces the lower part of the cavity, brine is the first product. After a time the salt-well may change to an oil-well.

### COAL-GAS.

190. *The Manufacture of Coal-Gas.*—The idea of turning hydrocarbon gases to the practical purposes of illumination occurred at about the same time to Murdock, in England, and Lebon, in France. This was in 1790; but for a long time there was a strong popular feeling against the new light. In England, it was not until 1812 that Parliament consented to charter a company for its manufacture. Even then the enterprise was looked upon as so visionary, that the act of incorporation was said to be granted in order to make a great experiment of a plan of such extraordinary novelty. In December, 1813, Westminster Bridge was first lighted with gas. From this time gas-lighting made the most rapid progress in England; and now the consumption of gas in London alone amounts to more than seven billions of cubic feet annually. To make this gas, eight hundred thousand tons of coal are required; while the length of the main pipes in the streets of the city is more than two thousand miles.

Paris was first lighted with gas in 1820. There, as in England, strong prejudices had to be overcome.

The most essential parts of the apparatus used in the making of coal-gas are represented in Figure 28.

Of course, it is only soft or bituminous coal that can be used for making gas. This coal is distilled in long

iron retorts, seen at the left of the figure. When charged with coal, these retorts are closed air-tight. They are

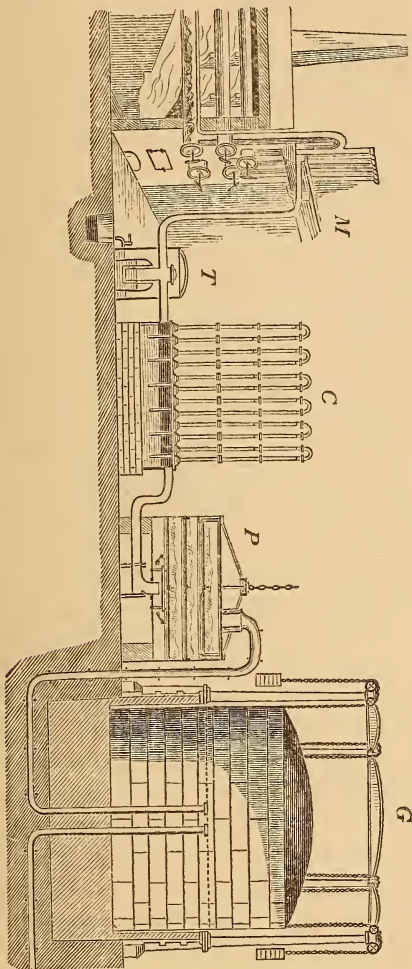


Fig. 28.

then heated to a very high temperature by the furnaces beneath.

The gaseous and volatile compounds, formed by the distillation of the coal, pass up through pipes (one of which may be seen leading from each retort) into a long horizontal pipe, *M*, called the *hydraulic main*. This is half full of water, into which the pipes from the retorts dip. The gas readily escapes from the pipes by bubbling up through the water; but, of course, it cannot return through the water.

The gas is carried from the hydraulic main through a pipe into a tank, *T*, called the *tar cistern*. By this time the more condensible gases have become liquid, and collect in the smaller vessel into which the pipe passes, and from which they overflow into the larger tank. From the latter they are drawn off at intervals. These condensed products are coal-tar and a liquid highly charged with ammonia, called *ammoniacal liquor*.

The uncondensed gases pass on through the series of upright pipes at *C*, called the *condenser*. Here they become still further cooled, and all the remaining condensible gases are reduced to the liquid state.

After leaving the condenser, the gas still contains, besides the compounds fit for illuminating purposes, the noxious compounds carbonic acid and hydric sulphide (49). These are removed in the *purifier*, *P*. It consists of a chamber with several perforated shelves, which are covered with slaked lime. In passing over this lime, the carbonic acid and hydric sulphide are absorbed, while the purified gas passes along into the *gasometer*, *G*.

This gasometer consists of a large sheet-iron bell-jar, which dips into a cistern of water. The latter is deep enough to allow the bell to be completely submerged, and filled with water. The bell is counterpoised with weights, and rises as the gas enters it.

From the gasometer the gas passes out, by the pipe at the right, into the streets and houses of the city.



## ILLUMINATION.

191. *Nature of Flame.*—We know that coal-gas burns with flame, while the solid carbon burns without flame. All combustible gases burn with flame.

We have seen that wood, when heated in a closed tube, gives off an inflammable gas; and the same is true of wax or tallow heated in the same way. Every *solid* which appears to burn with flame can thus be converted into an inflammable gas by means of heat. When these solids begin to burn, the heat developed is sufficient to generate this inflammable gas. It is this gas, and not the solid, which burns with flame.

Flame, then, is gas burning.

192. *A Solid and Heat are necessary to Illumination.*—The oxy-hydrogen flame (22) develops intense heat, but scarcely any light. If, however, a cylinder of lime be held in this flame, we get the brilliant *calcium*, or *Drummond* light.

We see, then, that a solid and an intense heat are necessary to illumination. (See Appendix, VI.)

193. *These two Conditions are fulfilled in the Burning of Coal-Gas.*—Illuminating gas, as we have seen, is a compound of carbon and hydrogen. If we hold a cold glass rod in a gas-flame, it becomes blackened with soot, showing that there is free carbon in the flame. We therefore conclude that the hydrogen of the gas combines with the atmospheric oxygen first. In doing so, it develops great heat.

In the manufacture of charcoal, the delicate cells of the wood are preserved intact; showing that the carbon, at the high temperature to which it is exposed in the process, has no disposition to melt. Its infusibility is its most marked characteristic (41).

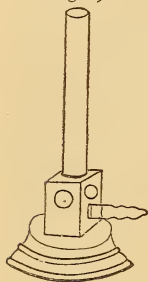
When the hydrogen of coal-gas combines with the oxygen of the air, the carbon is set free in a solid state. As the hydrogen consumes all the oxygen in the nearest layer of air, the carbon must delay a moment in the flame before it can get at oxygen to unite with. This finely divided solid thus becomes heated white-hot, and gives out light. This condition lasts but an instant. The next instant the carbon combines with atmospheric oxygen, and passes off as a colorless gas. As fast, however, as the carbon is consumed, a fresh supply is set free, and thus the light is constantly kept up.

The value, then, of coal-gas for illumination depends upon a most delicate adjustment of affinities.

Were the affinity of carbon for oxygen a little stronger than it now is, the carbon would burn at the same time with the hydrogen, and there would be no light in the flame. On the other hand, were the affinity of carbon for oxygen less than it is, the carbon would not burn at all, but, after developing light, would pass away from the flame in the form of soot.

194. *Bunsen's Lamp*.—The fact that carbon must remain an instant in the flame in the

Fig. 29.



solid state to develop light, is illustrated by Bunsen's burner. It is shown in Figure 29, and consists of a brass tube, near the bottom of which are four round holes, through which the air can pass into the tube. A second tube opens into the inside of the brass tube from the bottom, just on a level with these holes. The coal-gas passes into the larger tube, through this second tube. The air passes in through the holes at the same time, and the two gases become intimately mixed before they reach the top of the tube. Upon lighting the mixture as it escapes from the tube, it burns

with scarcely any light, but a good deal of heat. If we close the holes at the bottom of the tube, the gas burns with the ordinary luminous flame. In the first case, there is an excess of oxygen mixed with the coal-gas, so that there is enough to combine with the carbon as soon as it is set free, before it becomes sufficiently heated to develop light. In the second case, the carbon cannot get at the oxygen to combine with it, until it has passed through the burning layer of hydrogen, and thus become intensely heated.

195: *The Best Shape for a Gas-Flame.*—From what has been said, it is evident that the light of the flame is developed only at the surface, in the burning layer of hydrogen. The ordinary gas-burner is so made that the flame will be flat, in order that it may have as much surface as possible. The greater the surface, the greater the light developed.

196. *The Argand Burner.*—A sheet of paper will evidently present to the air just as much surface when it is bent round till the two edges meet, as when it is flat; while in the second case it is in a more compact form. So the ordinary gas-flame will present just as much surface, if its edges are bent round till they meet. In the Argand burner, this form is given to the flame, by supplying the gas through a circle of small holes in a hollow brass ring. A current of air passes up through this ring, furnishing oxygen to the inner surface of the flame.

197. *The Bude Light.*—If the interior of the ring of an Argand burner be closed, the flame becomes of a dull red color. Since no oxygen is supplied to the inner surface of the flame, the combustion is imperfect, and develops but a low degree of heat.

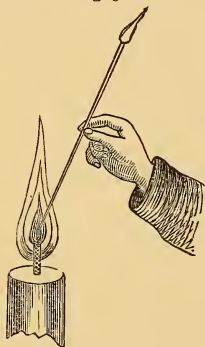
If, on the other hand, a stream of pure oxygen be supplied to the interior of the cylindrical flame, the flame diminishes in size; but the light becomes very intense,

and of a pure white color. The increased supply of oxygen increases the energy of the combustion of the hydrogen, and the intensity of the heat developed by it. In the first case, the carbon is heated only to a dull redness, while in the second case it is raised to a full white heat.

198. *A Burning Candle is a miniature Gas-Factory.*—We have seen that wax or tallow, when heated in a flask, is converted into an inflammable gas. This gas, in burning, produces water and carbonic acid; hence it must contain hydrogen and carbon, which are the main ingredients of coal-gas. This gas is in fact identical with coal-gas. The heat of the burning match converts some of the wax of the candle into gas, which takes fire, and in burning develops sufficient heat to convert more of the wax into gas; and thus the supply is kept up.

199. *The Flame of a Candle consists of three distinct Parts.*—In the flame of a candle there are three distinct parts: (1) the dark central zone, or supply of

Fig. 30.



unburnt gas surrounding the wick; (2) the luminous zone, or area of incomplete combustion; and (3) the non-luminous zone, or area of complete combustion. If we put one end of a small glass tube (see Figure 30) into the dark central zone, the unburnt gas will pass up the tube, and may be ignited at the other end. In the luminous part of the flame, as in the case of the gas-flame (193), the gas is not completely burnt, and carbon is separated in the solid state; and it is this carbon heated white-hot which renders the flame luminous. In the outer zone the supply of oxygen is greater; all the carbon is at once burnt to carbonic acid, and the flame here becomes non-luminous.

## SUMMARY.

Vegetable compounds may be broken up by *destructive distillation*.

In the preparation of charcoal, wood is decomposed into carbon and a number of volatile compounds.

When these volatile products are cooled and condensed, we obtain: (1) permanent gases; (2) a watery fluid; (3) a dark resinous fluid.

(1) The permanent gases are chiefly *marsh-gas*,  $H_4C$ , and *olefiant gas*,  $H_4C_2$ .

(2) The chief ingredient of the watery fluid is *pyroligneous acid*, or *wood vinegar*.

(3) The dark liquid is *wood tar*.

The most important ingredients of wood tar are *wood naphtha*, *creosote*, *paraffine*, and *asphalt*.

Mineral coal has probably been formed by the gradual decomposition of vegetable matter buried in the earth, and thus excluded from the air; the decomposition in many cases being hastened by the internal heat of the earth.

When the volatile products were allowed to escape freely, *anthracite* coal was formed; when they could not escape, *bituminous* coal was formed.

The volatile products often escaped into large cavities in the rocks, and on condensing gave rise to the celebrated *rock-oil*, or *petroleum*.

In some cases, this oil may have been formed by the decomposition of the vegetable matter at a temperature too low for its conversion into vapor, and may afterwards have been distilled by the internal heat of the earth.

The products of the destructive distillation of bituminous coal are more numerous than those of the distillation of wood. They are less rich in compounds containing *oxygen*, but richer in those containing *nitrogen*.

When the coal is distilled at a high temperature, a large amount of gas is obtained, and the liquid products are then called *tars*. When the coal is distilled at a low temperature, only a small amount of gas is obtained, and the liquid products are called *oils*.

When the gas obtained by the distillation of coal is purified, it forms the well-known *illuminating gas*.

The most important ingredients of *coal-tar* are *carbolic acid*, *ammonia*, *aniline*, *benzole*, *toluole*, *cumole*, *paraffine*, and *naphthaline*.

The *aniline colors* are prepared chiefly from benzole.

Only gases burn with flame. Solids that appear to burn with flame are first converted into a gas by heat, and this gas burns with flame.

The two conditions essential to illumination are the presence of a *solid* and intense *heat*.

The illuminating gases are all *hydrocarbons*, or compounds of hydrogen and carbon.

The hydrogen has the stronger affinity for oxygen, and burns first. The carbon is set free in a solid state, and delaying for an instant in the intense heat of the flame, before combining with oxygen, becomes luminous.

The light of the flame is increased (1) by increasing the surface of the flame, as in the ordinary gas-flame, and that of the Argand burner; and (2) by increasing the intensity of the combustion of the hydrogen, as in the Bude light.

The heat of the flame is increased by mixing oxygen with the gas before it burns, so that the carbon and hydrogen may burn together, as in the Bunsen burner.

The burning candle or oil-lamp is a miniature gas-factory.

The candle flame consists of three parts: (1) an inner zone of unburnt gases, surrounded by (2) a luminous zone of incomplete combustion, outside of which is (3) a non-luminous zone of complete combustion.



## FERMENTATION.

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200. *Causes of Fermentation.* — Complex organic compounds are often broken up into simpler compounds by the agency of growing plants. This process is called *fermentation*, and the organisms which effect it are called *ferments*. Different ferments give rise to different products, as alcohol, vinegar, etc. Most of these ferments are plants, but one at least is an animal; and this, strange to say, cannot live in contact with free oxygen, but flourishes in an atmosphere of hydrogen. In order that the ferment should grow, it must be supplied with proper food, especially with ammoniacal salts and alkaline phosphates. These are contained in the albuminous matter generally present in the liquid about to be fermented. In order that the fermentation should go on well, the temperature should be from 70° to 100°; at much higher, as at much lower temperatures, the vitality of the ferment is destroyed.

In many cases, spontaneous fermentation sets in without the apparent addition of any ferment: thus wine, beer, milk, etc., when allowed simply to stand exposed to the air, become sour or otherwise decompose. These changes are, however, not effected without the presence of vegetable or animal life, and are true fermentations. The *sporules*, or seeds of these living bodies, are always floating in the air, and on dropping into the liquid begin to propagate themselves, and in the act of growing evolve the products of the fermentation. If the liquid

be left only in contact with air which has been passed through a red-hot platinum tube, so that the living sporules are destroyed; or if the air be simply filtered by passing through cotton-wool, so that the sporules are prevented from coming into the liquid, it is found that the liquid may be preserved for any length of time without undergoing the slightest change.

The principal forms of fermentation are —

(1) The *alcoholic* fermentation, producing chiefly alcohol and carbonic acid.

(2) The *acetous* fermentation, producing acetic acid.

201. *Alcoholic Fermentation*. — Grape-sugar, if dissolved in presence of yeast (which is a plant and a ferment), undergoes fermentation, evolving mainly alcohol and carbonic acid:—



If cane-sugar be used, it takes up water and is converted into grape-sugar ( $\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} = \text{C}_{12}\text{H}_{24}\text{O}_{12}$ ), which is decomposed as above. The alcoholic fermentation is best effected at a temperature between  $77^\circ$  and  $86^\circ$ .

When the cereal grains are used for making alcohol, the starch of the grain is first converted into sugar. This change may be brought about by the action of sulphuric acid, as already explained (161); but, practically, it is usually effected by means of *diastase*.

202. *The Formation of Diastase in Growing Plants*.

— We have learned that the seed contains a supply of starch which is the food of the embryo plant until it is able to derive its sustenance from the earth and the air. We have learned, too, that this starch must be converted into sugar, in order that it may be dissolved in the sap of the plant and carried where it is needed for the purposes of growth. Let us now see how the starch is changed to

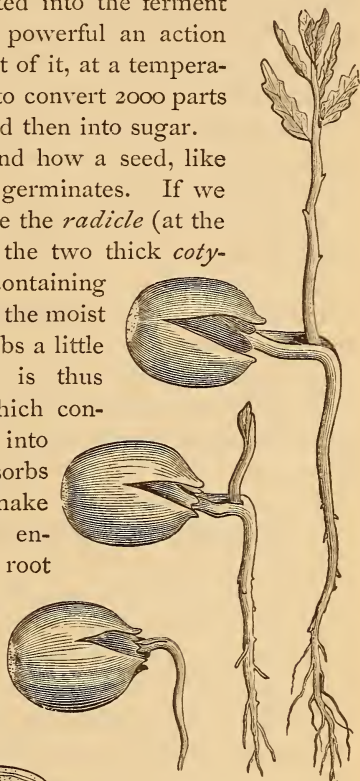
sugar. The seed contains more or less of the *nitrogenized* compound, *gluten* (142). This, under the influence of heat and moisture, begins to putrefy, and a portion of it is converted into the ferment *diastase*. This has so powerful an action upon starch, that one part of it, at a temperature of  $150^{\circ}$ , is sufficient to convert 2000 parts of starch into dextrine and then into sugar.

We can now understand how a seed, like the acorn (Figure 31), germinates. If we cut the acorn open, we see the *radicle* (at the right in the figure), and the two thick *cotyledons*, or seed-leaves, containing the starch and gluten. In the moist warm soil the acorn absorbs a little water, and the gluten is thus changed into diastase, which converts some of the starch into sugar. The radicle absorbs this sugar, and uses it to make woody fibre. It is thus enabled to thrust out a little root and begin to draw food from the earth, as well as from the starch in the seed. It next sends out the *plumule*, a little stem with its first leaves unfolding to the air and light. It



has now the means of  
ishment both from the  
earth and the air, and is no longer dependent upon the seed, which soon withers and perishes. Both root and stem are now rapidly developed (145-154), and thus at length the acorn becomes the mighty oak.

Fig. 31.



203. *Brewing*.—The brewer avails himself of this natural change in the germinating seed, and calls into action on a larger scale the chemical influence of diastase. The grain commonly used for the purpose is barley. This is first moistened in heaps, and spread out in a dark room to heat and sprout. When the gluten has begun to be transformed into diastase and the starch into sugar, so that the germ is about to burst from the envelop of the seed, the growth is arrested by heating the grain, and thus killing the embryo plant.

The *malt*, as the barley is now called, is next bruised, and soaked in warm water in the *mash-tub*. The water dissolves first the sugar which has already been formed in the seed, and then the diastase. The latter acts upon the rest of the starch of the seed, and of any raw grain which may be added to the malt, converting it into sugar, so that little, except the husk of the grain, is left undissolved; and the liquor, or *wort*, has a decidedly sweet taste.

The wort is now heated to boiling, to stop the action of the diastase, and to coagulate the albumen which has been dissolved out of the grain. At the same time, hops are added to the wort; and these, besides giving a bitter aroma to the liquid, help to clarify it. The boiled liquor is then filtered, and drawn off into shallow vessels, where it is cooled down to about 60°. Yeast is now added, and the mixture is allowed to ferment for six or eight days.

This fermentation is never allowed to continue until all the sugar is converted into alcohol. From one-half to three-fourths of it is decomposed; and the rest is left to give a sweet taste to the beer, and also to keep it from souring in the cask.

The liquor is next put into casks, where it goes through a second and much slower fermentation, which is essential to its preservation. When this fermentation is com-

pleted, the cask must be closed tight, to exclude the air, the oxygen of which would cause *acetous* fermentation. During this second fermentation, the carbonic acid is generated, to which the liquor owes its sparkling *effervescent* character.

204. *The Distillation of Spirits.* — When fermented liquors are boiled, the alcohol they contain rises in the form of vapor, mingled with steam. If the boiling be performed in a close vessel, and the vapors be led by a pipe into a cold receiver, they condense into a liquid, containing a large percentage of alcohol. This process is called *distillation*, and the apparatus for carrying it on is called a *still*.

If the alcoholic liquor thus obtained be re-distilled, or *rectified*, a spirit may be obtained, containing 90 per cent of alcohol and 10 of water. This is the strongest commercial alcohol. If this be mixed with calcic chloride, which has a strong affinity for water (113), and then be re-distilled, pure or *absolute* alcohol may be obtained.

We have seen that, in making beer, the fermentation of the wort is checked before all the sugar is converted into alcohol. But, in the manufacture of spirits from grain, the fermentation is prolonged until all the sugar is transformed into alcohol and carbonic acid. To leave any of it unchanged, would not only involve a loss of spirit, but, during the subsequent distillation, might injure the flavor of the spirit obtained.

The alcohol obtained from the fermentation of sugar is sometimes called *wine alcohol*, or *vinic alcohol*, to distinguish it from a large number of similar compounds, known to chemists as *alcohols*. Its symbol is  $C_2H_6O$ .

205. *Ether.* — When equal weights of strong alcohol and oil of vitriol are boiled in a retort, a colorless, fragrant, and highly volatile liquid passes over, called *ether*, or *sulphuric ether*,  $C_4H_{10}O$ . It is called *sulphuric*

ether, to indicate its origin, and to distinguish it from other analogous compounds called *ethers*.

When poured on the hand, ether produces a strong sensation of cold, owing to the rapidity with which it evaporates, rendering heat latent. It is very inflammable, and burns with a white flame. Its vapor forms explosive mixtures with air or oxygen. It dissolves oils, fats, and resins far more readily than alcohol does. It also dissolves sulphur, phosphorus, and iodine. When inhaled in sufficient quantity, its vapor is an *anæsthetic*, and was the first substance used for that purpose by physicians.

*Acetic ether* is obtained by distilling a mixture of alcohol, sulphuric acid, and acetic acid. It is used in medicine. If nitric acid be used, we get *nitric ether*, which is well known under the name of *sweet spirits of nitre*. Several of the ethers exist in a natural state in fruits, giving them their peculiar flavors.

206. *Acetic Acid*.—If alcohol, diluted with water, be mixed with a ferment, as yeast, and exposed to the air at ordinary temperatures, it is soon converted into *acetic acid*, or *vinegar*. The alcohol absorbs 2 atoms of oxygen, forming water and acetic acid:—



This process constitutes what is commonly called the *acetous fermentation*. Since the alcohol is oxidized, it is in a certain sense a *combustion* that takes place. It is, however, brought about by the influence of a ferment, known as the *vinegar-plant*, or *mother of vinegar*.

There are a great many methods of making vinegar on the large scale; but, for the most part, they are only different devices for exposing to the air as large a surface as possible of the alcoholic mixture. In one process, the liquid is allowed to trickle down through vats, filled with



flat pieces of wicker-work, piled one upon another. These are first watered with vinegar, or liquid partially converted into vinegar, and thus become covered with the germs of the vinegar-plant. Air is admitted through holes in the bottom of the vats, and passes out at the top, after giving up a part of its oxygen to the alcohol. Heat is produced by the oxidation, and this causes an upward draught, and quickens the circulation of air through the vats.

In another process, the weak alcoholic liquor trickles down through perforated casks, filled with beech shavings, which have been thoroughly scalded to remove all soluble matter. Air is admitted by holes around the lower part of the cask, and passes out at the top.

When vinegar is purified, and concentrated by distillation, it constitutes the *acetic acid* of commerce. This is prepared on a large scale from *pyroligneous acid*, or *wood vinegar* (174), which is obtained by the destructive distillation of wood.

207. *Bread-making*.—The making of bread in the ordinary way, by means of leaven or yeast, is an example of alcoholic fermentation.

When the grain of wheat is ground in a mill, and then sifted, it is separated into two parts, the *bran* and the *flour*. The bran is the outside harder part of the grain, which is not ground so readily, and, when ground, makes the flour darker. Both the bran and the flour consist mainly of gluten, starch, and water.

If the flour be mixed with water enough to moisten it thoroughly, the particles cohere and form a *dough*, which can be kneaded or moulded with the hand. It is the gluten of the flour which gives the tenacity to the dough.

A little leaven or yeast is added to the flour, either before it is mixed with water into a dough or in the

course of this process ; and the dough is then placed for some hours in a warm atmosphere, in order that it may *rise*. This rising is a fermentation, caused by the leaven or yeast. Leaven is the primitive ferment, and is simply a piece of moistened dough which has begun to putrefy. When brought in contact with a fresh portion of flour and water, it very quickly acts as a ferment, and develops fermentation in the whole mass. Yeast, as has been stated, is one of the vegetable growths which are ferments (200, 201).

The leaven or yeast soon begins to act on the gluten, starch, and sugar of the flour, and a portion of the sugar is converted into carbonic acid and alcohol in every part of the dough. The bubbles of gas, thus disengaged in the mass, form innumerable cavities, and make it light and porous.

The spongy dough is now put into a hot oven, where the fermentation and swelling are at first increased by the heat ; but when the whole has been heated to about  $212^{\circ}$ , the fermentation is suddenly arrested, and the mass becomes fixed in the form it has then attained. In the baking, some of the water is dissipated from the dough, the starch and gluten are partially *boiled*, and some of the starch is converted into dextrine. The brown, glossy appearance of the crust is due to this formation of dextrine (162). Most of the alcohol is driven off by the heat ; but a large amount of water (about 45 per cent of the weight of the bread) remains in the loaf after the baking.

There are various methods of making bread without fermentation, most of which depend on the liberation of carbonic acid from one of its compounds, by means of an acid. Bicarbonate of soda and muriatic acid are the materials sometimes used. Cream of tartar, which is a compound of tartaric acid (165), is often used as the acid.

The salt and acid are usually mixed with the dough, and the carbonic acid there set free; but in the manufacture of the so-called *aerated bread*, water charged with the gas is used in making the dough, as in the English method,\* or the gas itself is forced into the dough, as the process is conducted in this country.

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### SUMMARY.

Fermentation is the breaking up of complex organic compounds into simpler ones, by the agency of certain plants called *ferments*.

The *alcoholic* fermentation takes place in sugar, and produces alcohol and carbonic acid.

In making alcoholic liquors from grain, the starch of the grain is converted into sugar, by the action of *diastase*, as in the germination of seeds. The sugar is then converted into alcohol by the use of a ferment, as yeast.

The alcohol of fermented liquors may be separated from the water, and concentrated by *distillation*.

By the action of acids upon alcohol, important compounds called *ethers* are obtained.

The *acetous* fermentation takes place in alcohol, which undergoes oxidation, producing vinegar, or acetic acid.

The making of bread with yeast is an example of alcoholic fermentation.

\* See article on *Aerated Bread* in "Chambers's Encyclopædia;" also Fownes's "Chemistry," 10th edition (London, 1868), page 605.



## APPENDIX.

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### I.

#### QUANTIVALENCE.

The atoms of the different elements differ not only in their weight and the intensity of their affinity, but also in their *combining capacity*, or the *number* of their *affinities*. Thus an atom of chlorine is able to attach itself to only one atom of hydrogen: while an atom of oxygen can attach itself to two atoms of hydrogen; and an atom of carbon, to four atoms of hydrogen. The combining capacity of an atom is usually called its *atomicity*, or *quantivalence*. It may be represented graphically by means of dots and dashes: the latter being used when the affinity is exerted in holding together two atoms; and the former, when it is not so employed. Thus H-O-H indicates that an atom of oxygen has two affinities, and an atom of hydrogen one, and that these affinities are employed in holding the atoms of hydrogen to that of oxygen. H· and ·O·, on the other hand, indicate that the affinities of the two atoms are unemployed.

As regards their atomicity, the elements have been found to fall into six classes: those whose atom has *one* unit of combining capacity, called *univalents*, or *monads*; those whose atom has *two* units, called *bivalents*, or *dyads*; those whose atom has *three* units, called *trivalents*, or *triads*; those whose atom has *four* units, called *quadrivalents*, or *tetrads*; those whose atom has *five* units, called *quinquivalents*, or *pentads*; and those whose atom has *six* units, called *sexivalents*, or *hexads*.

Those of *uneven* equivalence are usually classed together as *perissads*; and those of *even* equivalence, as *artiads*.

In some cases, a part of the combining units of an atom often remain dormant, so that it seems to have two equivalences.

TABLE.

The elements are grouped according to their quantivalence, which is designated by the Roman numerals. Those marked with a \* are *non-metals*; all the others are *metals*. The names of the rarer elements are in italics.

PERISSAD ELEMENTS.	Atomic Weights.	Symbols.	Quanti- valence.	ARTIAD ELEMENTS.	Atomic Weights.	Symbols.	Quanti- valence.
Hydrogen	1.0	<i>H</i>	I	Copper	63.4	<i>Cu</i>	II
Fluorine*	19.0	<i>F</i>	"	Mercury	200.0	<i>Hg</i>	"
Chlorine*	35.5	<i>Cl</i>	"	Calcium	40.0	<i>Ca</i>	"
Bromine*	80.0	<i>Br</i>	"	Strontium	87.6	<i>Sr</i>	"
Iodine*	127.0	<i>I</i>	"	Barium	137.0	<i>Ba</i>	"
<i>Lithium</i>	7.0	<i>Li</i>	"	Lead	207.0	<i>Pb</i>	"
Sodium	23.0	<i>Na</i>	"	Magnesium	24.0	<i>Mg</i>	"
Potassium	39.1	<i>K</i>	"	Zinc	65.2	<i>Zn</i>	"
<i>Rubidium</i>	85.4	<i>Rb</i>	"	<i>Indium</i>	72.0	<i>In</i>	"
<i>Cæsium</i>	133.0	<i>Cs</i>	"	Cadmium	112.0	<i>Cd</i>	"
Silver	108.0	<i>Ag</i>	"	<i>Glucinum</i>	9.3	<i>G</i>	"
<i>Thallium</i>	204.0	<i>Tl</i>	I or III	<i>Yttrium</i>	61.7	<i>Y</i>	"
Gold	197.0	<i>Au</i>	III	<i>Erbium</i>	112.6	<i>E</i>	"
Boron*	11.0	<i>B</i>	"	<i>Cerium</i>	92.0	<i>Ce</i>	"
Nitrogen*	14.0	<i>N</i>	III or V	<i>Lanthanum</i>	93.6	<i>La</i>	"
Phosphorus*	31.0	<i>P</i>	"	<i>Didymium</i>	95.0	<i>D</i>	"
Arsenic*	75.0	<i>As</i>	"	Nickel	58.8	<i>Ni</i>	"
Antimony*	122.0	<i>Sb</i>	"	Cobalt	58.8	<i>Co</i>	"
Bismuth*	210.0	<i>Bi</i>	"	Manganese	55.0	<i>Mn</i>	II or IV
<i>Vanadium</i>	51.37	<i>V</i>	"	Iron	56.0	<i>Fe</i>	"
Uranium	120.0	<i>U</i>	"	Aluminium	27.4	<i>Al</i>	"
<i>Columbium</i>	94.0	<i>Cb</i>	V	Chromium	52.2	<i>Cr</i>	"
<i>Tantalum</i>	182.0	<i>Ta</i>	"	<i>Ruthenium</i>	104.4	<i>Ru</i>	"
				<i>Osmium</i>	199.2	<i>Os</i>	"
				<i>Rhodium</i>	104.4	<i>R</i>	"
				<i>Iridium</i>	196.0	<i>Ir</i>	"
				<i>Palladium</i>	106.6	<i>Pd</i>	"
				Platinum	197.4	<i>Pt</i>	"
				Titanium	50.0	<i>Ti</i>	"
				Tin	118.0	<i>Su</i>	"
				<i>Zirconium</i>	89.6	<i>Zr</i>	IV
				<i>Thorium</i>	231.4	<i>Th</i>	"
				Silicon*	28.0	<i>Si</i>	"
				Carbon*	12.0	<i>C</i>	"
ARTIAD ELEMENTS.							
Oxygen*	16.0	<i>O</i>	II				
Sulphur*	32.0	<i>S</i>	II or VI				
<i>Selenium*</i>	79.4	<i>Se</i>	"				
<i>Tellurium*</i>	128.0	<i>Te</i>	"				
<i>Molybdenum</i>	96.0	<i>Mo</i>	VI				
Tungsten	184.0	<i>W</i>	"				

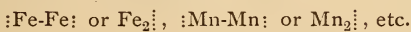


When all the combining units of the atoms are employed, the molecule is said to be *saturated*; otherwise, *unsaturated*. Thus  $\text{H-Cl}$ ,  $\text{H}_2=\text{O}$ ,  $\text{C}\equiv\text{O}_2$ , and  $\text{H}_4\equiv\text{N-Cl}$  are saturated molecules, but  $\text{:C=O}$ ,  $\cdot\text{N}\equiv\text{O}_2$ ,  $\text{:S}\equiv\text{O}_2$ , are unsaturated molecules. These unsaturated molecules can enter directly into combination with other atoms or groups of atoms, while the saturated molecules cannot. Thus  $\text{:C=O}$  can unite directly with an atom of oxygen, forming  $\text{O=C=O}$ , or  $\text{C}\equiv\text{O}_2$ ; but  $\text{C}\equiv\text{O}_2$ , cannot take any additional atom to itself, for the simple reason that there is no remaining point of attachment

Such unsaturated molecules as the above are usually called *compound radicals*. When they enter into combination, they are supposed to exist in the molecule as a distinct group, or, as it were, a molecule within a molecule; just as Saturn with his group of rings and moons exists as a distinct system within our solar system. The compound radicals already given are known in the free state; but there are many such groups, which are supposed to exist in compounds, but have never yet been obtained free.

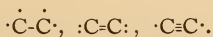
The equivalence of a radical is always equal to the number of its uncombined units.

In some cases, the atoms of the same element often unite by a part of their affinities, and thus form *elementary radicals*. Thus in all the mercurous and cuprous compounds, we find the dyad radicals  $\text{Hg}_2$  and  $\text{Cu}_2$ , formed by the union of two atoms,  $\cdot\text{Hg-Hg}\cdot$ , or  $\text{Hg}_2\cdot$  and  $\cdot\text{Cu=Cu}\cdot$ , or  $\text{Cu}_2\cdot$ . Also in the ferric, manganic, chromic, and aluminic compounds we have the sexivalent radicals  $\text{Fe}_2$ ,  $\text{Mn}_2$ ,  $\text{Cr}_2$ , and  $\text{Al}_2$ , formed thus:—

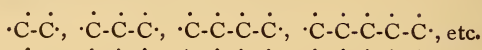


But, of all the elements, the atoms of the tetrad carbon manifest the greatest disposition to unite with one another by a part of their affinities, especially when their remaining affinities are satisfied by atoms of hydrogen.

Thus two atoms of carbon may unite with each other by one, two, or three of their affinities, as shown by the following graphic formulas:—



Again, into each one of these radicals may be introduced one or more carbon atoms; thus:—



## II.

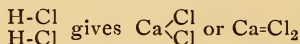
### MOLECULAR STRUCTURE.

1. *Types.* By the locking together of multivalent atoms, as was illustrated in the case of carbon in the last section, it is seen that a great number of atoms may be introduced into a molecule. This number sometimes reaches several hundred. Yet all these molecules seem to be constructed after three or four simple patterns, or *types*; the atoms of the simple typical molecule being, in the case of the more complex molecules, replaced by more or less complex radicals.

The most important molecular types are those of *hydrogen* and of *water*.

The symbol of the first is H-H. By replacing one of the atoms of hydrogen in this molecule with an atom of each of the monad non-metals, we get (without change of molecular structure) the hydracids H-Cl, H-I, H-Br, and H-F. By replacing the second atom of hydrogen in any one of these acids by an atom of any of the monad metals, we get (still without any change of molecular structure) such *haloid*\* salts as Na-Cl, K-Br, Ag-I, etc.

By replacing one atom of hydrogen in each of two molecules of any one of their acids by an atom of any of the dyad metals, we shall get (by a simple condensation of two molecules into one) the haloid salts of the dyad metals. Thus



By a similar condensation carried to a greater degree, we may get the haloid salts of the metals and metallic radicals of higher equivalence.

\* Salts formed from the hydracids are often called *haloid* salts.

It will thus be seen, that the hydracids and the haloid salts all belong to the molecular type of *hydrogen*, with or without *condensation*.

The molecule of *water* may be written  $\text{H-O-H}$ , or  $\text{H}_2=\text{O}$ .

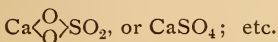
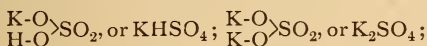
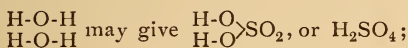
By replacing the first atom of hydrogen by an atom of a monad metal, we may get (without any change in molecular structure) such metallic hydrates as  $\text{K-O-H}$ , or  $\text{KHO}$ , and  $\text{Na-O-H}$ , or  $\text{NaHO}$ , etc.

By replacing both atoms of hydrogen by atoms of the monad metals, we may get (still without any change of structure) the metallic oxides  $\text{K-O-K}$ , or  $\text{K}_2\text{O}$ ,  $\text{Na-O-Na}$ , or  $\text{Na}_2\text{O}$ , etc.

By replacing one or both atoms of hydrogen by the univalent radical  $\text{NO}_2$ , we may get  $\text{H-O-NO}_2$ , or  $\text{HNO}_3$  (nitric acid), or  $\text{NO}_2\text{-O-NO}_2$ , or  $\text{N}_2\text{O}_5$  (nitric anhydride), of precisely the same molecular structure as water.

Again, we may replace one of the atoms of hydrogen by an atom of a monad metal, and the other by the univalent radical  $\text{NO}_2$ , with no change of molecular structure, and thus get the salt  $\text{K-O-NO}_2$ , or  $\text{KNO}_3$  (potassic nitrate).

By a simple condensation of one molecule of the water type, we get other salts of the monad and dyad metals. Thus:—



In a similar manner, it may be shown that all the ternary acids and salts, and all the metallic hydrates and oxides, and a host of other compounds, belong to the water type, with or without condensation.

[For further information on this point, see the "Elements of Chemistry" of the "Cambridge Course of Physics," pp. 79-84 and 345-352.]

2. *Substitution*. — "When cotton-wool is dipped in strong nitric acid (rendered still more active by being mixed with twice its volume of concentrated sulphuric acid), and afterwards

washed and dried, it is rendered highly explosive; and, although no important change has taken place in its outward aspect, it is found on analysis to have lost a certain amount of hydrogen, and to have gained from the nitric acid an equivalent amount of nitric peroxide,  $\text{NO}_2$ , in its place."

$\text{C}_{12}\text{H}_{20}\text{O}_{10}$  (cotton) becomes  $\text{C}_{12}\text{H}_{14}(\text{NO}_2)_6\text{O}_{10}$  (gun-cotton).

Under the same conditions, glycerine undergoes a like change, and is converted into the explosive nitro-glycerine.

$\text{C}_6\text{H}_{16}\text{O}_6$  (glycerine) becomes  $\text{C}_6\text{H}_{10}(\text{NO}_2)_6\text{O}_6$  (nitro-glycerine).

So also the hydro-carbon, naphtha, called *benzole*, is changed into nitro-benzole.

$\text{C}_6\text{H}_6$  (benzole) becomes  $\text{C}_6\text{H}_5(\text{NO}_2)$  (nitro-benzole).

"The last compound is not explosive, and the explosive nature of the first two is, in a measure, an accidental quality, and is evidently owing to the fact, that into an already complex structure there have been introduced, in place of the indivisible atoms of hydrogen, the atoms of a highly unstable radical, rich in oxygen. The point of chief interest for our chemical theory is, that this substitution does not alter, at least profoundly, the outward aspect of the original compound. Every one knows how closely gun-cotton resembles cotton-wool. In like manner, nitro-glycerine is an oily liquid, like glycerine; and nitro-benzole, although darker in color, is a highly aromatic, volatile fluid, like benzole itself. Products like these are called *substitution products*; and they certainly suggest the idea that each chemical compound has a certain definite structure, which may be preserved even when the materials of which it is built are, in part, at least, changed. If, in the place of firm iron girders, we insert weak wooden beams, a building, while retaining all its outward aspects, may be rendered wholly insecure. And so the explosive nature of the products we have been considering is not at all incompatible with a close resemblance, in outward aspects and internal structure, to the compounds from which they are derived."

3. *Isomorphism*. — "Closely associated with the facts of the last section, which find their chief manifestation in substances

of organic origin, are the phenomena of *isomorphism*, which are equally conspicuous among artificial salts and native minerals. There seems to be an intimate connection between chemical composition and crystalline form, and two substances which, under a like form, have an analogous composition, are said to be *isomorphous*." The following minerals are isomorphous: —

Calcite, or calcic carbonate,	$\text{CaCO}_3$
Magnesite, or magnesian carbonate,	$\text{MgCO}_3$
Chalybdite, or ferrous carbonate,	$\text{FeCO}_3$
Diallogite, or manganous carbonate,	$\text{MnCO}_3$

"The most cursory examination of these symbols will show that they differ from each other only in the fact that one metallic atom has been replaced by another. It is not, however, every metallic atom which can thus be put in without altering the form. This is a peculiarity which is confined to certain groups of elements, which for this reason are called *groups of isomorphous elements*. Moreover, as a rule, there is a close resemblance between the members of any one of these groups in all their other chemical relations. These facts, like those of the last section, tend to show that the molecules of every substance have a determinate structure, which admits of a limited substitution of parts without undergoing essential change, but which is either destroyed or takes a new shape when, in place of one of its constituents, we force in an uncomformable element. A well-known class of artificial salts called the *alums* affords even a more striking illustration of the principles of isomorphism than the simpler examples we have chosen."

4. *Isomerism, Allotropism, and Polymorphism*. — The same atoms may be grouped together in different ways, so as to form different molecules, which present essentially distinct qualities. Hence distinct substances may have the same composition; and they are then said to be *isomeric*, and the phenomenon is called *isomerism*. Thus, common sugar and gum arabic have exactly the same composition,  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ , and are *isomeric*.

When, however, the differences are not sufficiently great to justify a distinct name, the two bodies are said to be different *allotropic* states of the same substance, and the phenomenon is

called *allotropism*. Thus, there are three varieties of *tartaric acid* which differ in their action on polarized light, but which are in almost every other respect identical.

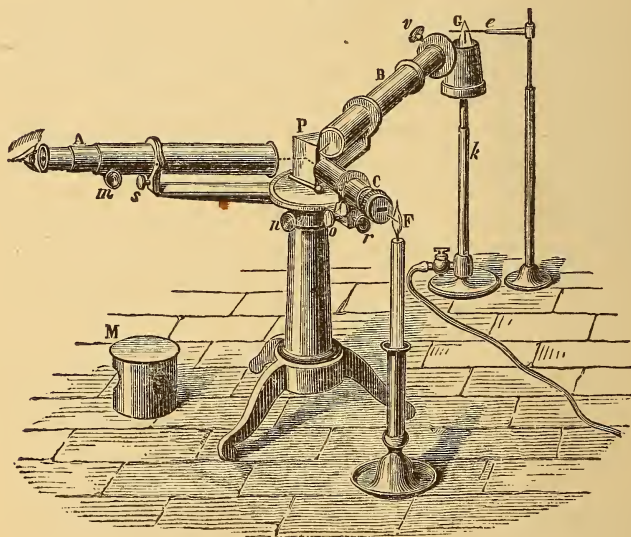
Sometimes a substance *crystallizes* in fundamentally different forms, as calcic carbonate in the minerals *calcite* and *aragonite*. This phenomenon is called *polymorphism*, and is invariably accompanied by a marked difference of properties.

### III.

#### THE SPECTROSCOPE AND ITS APPLICATIONS IN CHEMISTRY.

1. *The Spectroscope.* — This instrument (Figure 31 *a*) consists of a triangular piece of glass, *P*, called a *prism*, and three tubes,

Fig. 31 *a*.



*A*, *B*, and *C*. The tube *A* is an ordinary telescope. The tube *B* has a narrow slit in its outer end, through which a beam of light is admitted. This beam is concentrated by a lens upon



the prism *P*. The tube *C* has at its outer end a fine scale marked on glass. The light from the candle *F* shines through this glass, and is reflected by the face of the prism into the telescope *A*, so that on looking into this telescope an enlarged image of the scale is seen. The light from the tube *B*, on passing through the prism, is *dispersed* into what is called a *spectrum*, which is examined by means of the telescope *A*. With ordinary candle-light this spectrum is a continuous band of colored light, made up of the seven *prismatic colors*, red, orange, yellow, green, blue, indigo, and violet.

This simple instrument was invented in 1859, by two German professors, Bunsen and Kirchhoff, and it has already led to most remarkable discoveries in both Chemistry and Astronomy.

2. *Spectra of Incandescent Gases*. — The spectrum of an ordinary candle or gas-flame is called a *continuous* spectrum. If, however, we dip a platinum wire into a solution of some sodic salt, and hold it in the colorless flame of a Bunsen's lamp, so as to color it with incandescent sodium vapor, we shall get a spectrum, consisting of a single yellow line, as shown at III. in the chromolithic plate at the beginning of this book. Color the flame in a similar manner with incandescent *potassium* vapor, and we get a spectrum like II. in the plate, *continuous* in the middle, with a bright line at each end. The incandescent vapors of the rare metals *cæsium* and *rubidium* give spectra like IV. and V. in the plate.

As a rule, the spectra of incandescent gases are broken, or *discontinuous*; that is, made up of bright lines separated by dark spaces. The spectrum of each element is unlike that of every other element, either in the number or the position of its bright lines, and usually in both.

The position of these lines can be ascertained with great accuracy by means of the scale, which is seen in the telescope in the same position as the spectrum; and for the same substance the position of the bright lines is always the same.

3. *Use of the Spectroscope in Chemical Analysis*. — We have now seen that, as a rule, the spectra of incandescent gases are discontinuous, and that each is peculiar to itself. No matter how many gases there may be in the flame, each will give its

own lines, and no others. Hence we have in the spectroscope a valuable means of recognizing the elements which exist in a substance of unknown composition. We have merely to heat its vapor to incandescence, examine it with the spectroscope, read off the position of the bright lines on the scale, and compare it with the position of the bright lines given by known elements.

This method of chemical analysis by spectrum observation is of wonderful delicacy. The .000000005 of a grain of a sodic compound can easily be detected in this way. Sodium is found to be always present in the air. All bodies that are exposed to the air show the yellow sodium line when heated. Of lithium .00000016 of a grain can be detected. This element was formerly known to exist in only four minerals: it is now found by spectrum analysis to be one of the most widely distributed of elements. It exists in almost all rocks, in sea and river water, in the ashes of most plants, in milk, human blood, and muscular tissue.

One of the first fruits of spectrum analysis was the discovery by Bunsen, in 1861, of the two new elements, *cæsium* and *rubidium*. They were found in the mineral waters of Durkheim; forty-two tons of which had to be boiled down in order to obtain two hundred grains of the metals.

It was by spectrum analysis also that *thallium* was discovered by Crookes, in 1861; and *indium*, by Reich and Richter, in 1864. The spectrum of the former metal consists of a splendid green line, and its name is derived from *θαλλός* (Latin, *thallus*), a green twig; that of the latter is made up of two *indigo* bands, whence the name *indium*.

4. *Use of the Spectroscope in the Bessemer Process.* — Not only has the spectroscope proved valuable in the analysis of chemical compounds, and in the discovery of new elements, but it has also become of important service to the manufacturer of steel. In the "Bessemer process" (page 55), every thing depends upon shutting off the blast of air at just the right moment. If the blast be continued ten seconds beyond the right moment, the charge becomes too viscid to be poured from the *converter*; if it be stopped ten seconds too soon, the steel contains so

much carbon that it will crumble under the hammer like cast-iron.

The flame undergoes various changes during the process, but only workmen of great skill and experience can tell by a simple inspection of the flame just when to shut off the air. By the use of the spectroscope, however, any one can tell with the utmost exactness the proper moment to stop the blast. After showing a great number and variety of bright and dark bands, the spectrum all at once becomes *continuous*, and experience has shown that this is the precise moment for shutting off the air.

5. *Use of the Spectroscope for detecting Adulterations, etc.* — When light is allowed to pass through certain solutions, as that of potassic permanganate, or through certain coloring substances, as madder, magenta, or chlorophyl, and is then examined by the spectroscope, the spectrum is found to be crossed by dark bands, called *absorption bands*. As each of these substances gives absorption bands peculiar to itself, we have in these bands a ready means of recognizing the substance, and also of detecting adulterations in a medicinal compound or in a dye-stuff. The purity of wines may thus be tested, since the coloring-matter of the grape gives absorption bands wholly unlike those of the adulterations used.

By means of the spectroscope, too, the .001 part of a grain of the coloring-matter in a blood-stain can be detected with absolute certainty. Hence, the instrument has become a most valuable aid in medico-legal investigation.

[For the applications of the Spectroscope in *Astronomy*, see the "Handbook of the Stars" or the "Elements of Astronomy," published in the "Cambridge Course of Physics."]

## IV.

### DISSOCIATION.

1. *Heat tends to overcome Cohesion and Affinity.* — We have seen that sensible masses of matter are made up of insensible molecules, and these molecules of yet smaller masses called atoms. The atoms of a molecule are held together by *affinity*; and the molecules, in solids and liquids, by a force called *co-*

*hesion.* Heat may partially or wholly overcome this cohesive force, and convert a solid into a liquid, and a liquid into a gas.

We have further seen that heat will in some cases break up the molecules themselves, and thus decompose the compound, as in the preparation of oxygen from potassic chlorate.

In 1857, the celebrated French chemist, Henri St. Claire Deville, first called attention to the fact that any substance may be decomposed if sufficiently heated. This spontaneous decomposition of substances under the influence of heat he calls *dissociation*. He thinks that the dissociation of compounds, like the melting of solids or the boiling of liquids, takes place at a definite temperature, which is different for each substance. Thus nitric anhydride decomposes spontaneously at the ordinary temperature; ammoniac carbonate dissociates at  $60^{\circ}$  C., and ammonia gas at a red heat. He thinks that water is dissociated at a temperature of about  $1000^{\circ}$  C.

In the case of water, and most other compounds, the fact of dissociation is not ordinarily observable, because on cooling down the atoms reunite so as to form the original compound again. Thus, if heated above  $1000^{\circ}$  C., the vapor of water is really separated into hydrogen and oxygen atoms, but on cooling down they again unite with each other so as to form water.

It would at first seem that the theory that heat tends to overcome affinity, and to separate the atoms of a molecule as well as the molecules themselves, is at variance with certain well-known facts; as the refusal of hydrogen and oxygen to enter into combination till heated. In this and many other cases heat seems to aid affinity rather than oppose it. A little consideration will, however, show that these cases do not necessarily conflict with the theory. We must remember that the molecules of hydrogen and oxygen, as well as the molecules of water, are made up of atoms, and that these atoms must separate or *dissociate* before they can enter into new combinations so as to form new molecules. An element may, according to our view, undergo dissociation as well as a compound. At a sufficiently high temperature, all molecules, whether elementary or compound, would be broken up, and all matter be resolved into atoms. The first effect of the heat then, in the above case, is to disso-

ciate the atoms in the molecules of hydrogen and oxygen; but as the point of dissociation of these gases is below that of water, the atoms of hydrogen thus set free combine with those of oxygen and form water. At a still higher temperature the water is dissociated, but on cooling down the dissociated hydrogen atoms unite with those of oxygen before they are sufficiently cool to reunite with each other, so as to form ordinary hydrogen gas.

If by any means the atoms of hydrogen could, after the dissociation of water, be separated from those of oxygen, we should in the end obtain ordinary hydrogen and oxygen gases.

On the 18th of March, 1861, Deville published a series of researches\* upon the influence exerted by certain porous vessels upon the composition of the gases that pass through them. A porous porcelain tube was placed in the interior of a larger glass tube, and each was provided with separate gas-escaping tubes. On causing hydrogen to pass through the interior tube, and carbonic acid gas through the outer space, the two gases were found to exchange places, and an inflammable gas collected at the end of the carbonic acid tube. It thus appeared that the hydrogen passed through the pores of the porcelain tube, and was replaced by the carbonic acid.

The previous experiment with hydrogen and carbonic acid was repeated with steam and carbonic acid. In a furnace capable of producing a heat of  $1100^{\circ}$  to  $1300^{\circ}$  C. he placed two tubes; through the interior tube of porous clay he forced a gentle current of steam, and through the annular space of the outer tube a stream of carbonic acid gas. A part of the vapor of water is decomposed spontaneously, or dissociated, in the tube of porous clay; the hydrogen is filtered through to the annular space (as in the previous experiment with carbonic acid and pure hydrogen), and the oxygen remains in the inner tube, mixed with a considerable quantity of carbonic acid. Deville obtained in this way one cubic centimetre of gas to one gramme of water. The separation of the oxygen is thus accomplished by physical agency.

\* This account of Deville's experiments is condensed from an article written by Professor Charles A. Joy, of Columbia College, New York.

It will thus be seen that Deville was able to dissociate the oxygen and hydrogen of water, and to obtain these gases in a separate condition. His experiment suggests a method for the accomplishment of this desirable result in an economical manner. By employing the carbonic acid resulting from the fire used to generate the steam, we can conceive of a simple system of tubes that would enable us to dissociate water in a way that would yield hydrogen and oxygen for light and heat.

Devilie published an account of another series of experiments, February 13, 1865. He conducted these upon a somewhat different plan. He had early observed that, although compounds were dissociated at high temperatures, yet, on cooling, the elements recombined before they could be collected; it therefore became necessary for him to devise some plan to obviate this difficulty. He hit upon the following expedient: Through the centre of the system of tubes he arranged a tube for conducting a constant stream of cold water. While the outer vessel was raised to the highest temperature of the furnace the inside was cold, and thus two surfaces were exposed to the gas, one for dissociating it, the other for condensing one of the constituents before it could recombine. In this way he succeeded in dissociating sulphurous acid at  $1200^{\circ}$  C. into sulphur and sulphuric anhydride; muriatic acid into hydrogen and chlorine; carbonic oxide into carbon and carbonic acid; and carbonic acid into carbonic oxide and oxygen.

2. *The Chemical Action of Light.* — Several compounds are decomposed under the influence of light. This is especially the case with the salts of silver. When these salts are in contact with organic matter and exposed to the light, they *blacken* more or less rapidly. This blackening is due to a decomposition effected by the light. Some of the silver is set free in a very finely divided state, and thus appears black. The chemical action of light is quite analogous to that of heat. In this and other cases it acts against affinity, and tends to break up the molecules of a compound.

In the case of hydrogen and chlorine, it appears to aid affinity; for if we place a mixture of these two gases in direct sunshine, they unite with a violent explosion, while in the dark they will



remain mixed any length of time without combination. But here also the direct action of the light undoubtedly tends to separate the atoms from each other in the molecules of hydrogen and chlorine, so that they may combine anew to form muriatic acid. The strong disposition of the hydrogen and chlorine atoms to combine doubtless aids the light.

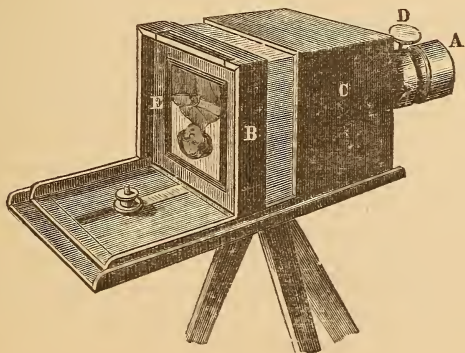
As a rule, the more refrangible the rays, the stronger their chemical action; but different substances are affected by rays of different refrangibility. Tyndall's recent experiments with vapors indicate that the decomposition is effected by the particular rays which the body *absorbs*.

## V.

## PHOTOGRAPHY.

1. *The Camera*. — If a lens be placed at an opening in a shutter of a darkened room, and a screen be placed at a proper distance behind it, a beautiful inverted image of the objects outside the window will appear on the screen. The arrangement just described is called a *camera obscura*, and photography is the art of fixing the image of the camera permanently to the surface upon which it falls. This is done by the chemical action of light.

The form of camera used by photographers is shown in Figure 31 *b*. The lenses for forming the image are in the tube *A*, and

Fig. 31 *b*.

the screen for receiving it is a piece of ground glass, *E*. This screen is capable of a backward and forward movement, and is adjusted so that the image upon it is perfectly clear and distinct. The glass plate is then removed, and a surface sensitive to the action of light is put in its place.

The various photographic processes may be considered under three heads: photography *on metal*, photography *on paper*, and photography *on glass*.

2. *Photographs on Metal*.—It was in the year 1839 that the problem of taking pictures by light was first successfully solved by a Frenchman named Daguerre.

The *Daguerreotype* picture is taken on a plate of copper coated with silver. The plate is first carefully polished, and then rendered *sensitive* by exposing its silvered surface to the vapor of iodine, which forms upon it a thin layer of argentic iodide. If the picture is to be taken quickly, the surface must be made still more sensitive by the action of bromine. All these operations must be performed in a room lighted by a candle. The plate is now put into a little wooden case, and exposed in the camera. After a little time, it is removed to a darkened room. No change perceptible to the eye has taken place. But when the plate is exposed to the vapor of mercury, an image appears exactly like that formed in the camera. The mercury condenses upon those parts of the plate that have been most strongly illumined, and thus *develops* the picture which before was *latent*. The action of the light gives the molecules of the argentic iodide a tendency to decompose, and the tendency of the mercury to unite with the silver completes the decomposition of these molecules. In the shades of the picture, the molecules of the iodide have acquired no tendency to break up, and those parts are not attacked by the mercury.

If, after the development of the picture, the plate were exposed to the light, the iodide on all parts of the surface not attacked by the mercury would gradually blacken, and the picture become obliterated. In order to *fix* the picture, it is necessary to dissolve and remove this iodide, which is usually done by a solution of sodic hyposulphite.

The picture is next *toned* by immersing the plate in a solution

of auric chloride. Some of the gold unites with the mercury and silver of the parts attacked, and greatly increases the intensity of the lustre.

The *lights* of the Daguerreotype picture consist of the amalgam; and the *shades*, of metallic silver.

3. *Photographs on Paper*. — Photographs on paper are ordinarily printed from *negatives* on glass.

If gun-cotton be put into a mixture of alcohol and ether, it dissolves and forms *collodion*. If this solution is poured over any surface, the alcohol and ether quickly evaporate, leaving a film of solid collodion behind.

To obtain a sensitive surface on glass, a solution of collodion is first impregnated with potassic iodide, or a mixture of potassic iodide and ammoniac bromide, and poured out upon the surface of a glass plate, so as to coat it with a thin film. The plate thus coated is dipped into a bath of argentic nitrate, so as to form a film of argentic iodide, or a mixture of argentic iodide and bromide. The plate is now exposed a short time in the camera, and again removed to a darkened room. As before, no image is perceptible. The light has not decomposed the compounds of silver, but merely given them a disposition to decompose. Their decomposition is completed, and the picture developed, by pouring over the plate a solution of ferrous sulphate or of pyrogallic acid. The picture is next fixed by dissolving off the argentic iodide from the unaffected part by means of the solution of sodic hyposulphite.

The glass is rendered less transparent by the presence of the metallic silver: hence, when viewed by transmitted light, the lights of the image appear dark; and the shades, light; and the picture is therefore said to be a *negative*. From this negative picture any number of *positive* pictures may be printed on paper. For this purpose, paper is impregnated with argentic chloride, by dipping it first into a solution of common salt (sodic chloride), and then into a bath of argentic nitrate. The negative is then placed on a sheet of this paper in a copying-frame, and exposed to the action of light. The chloride gradually blackens, and most rapidly where the glass is most transparent. In this way the tints of the negative are reversed, and the picture

becomes a *positive*. After sufficient exposure, the picture is *fixed* by dissolving off the remaining chloride by a solution of sodic hyposulphite, and *toned* by immersing it in a bath of auric chloride.

4. *Photographs on Glass*.—The picture on glass, which appears negative by transmitted light, will become positive if it be backed with a coating of black varnish or a piece of black cloth, so that it shall be seen by reflected light.

Beautiful positive pictures on glass may be obtained by the following process: prepare the plate in the same way as for negatives, but expose it a much shorter time in the camera; develop the picture by pouring over it a solution of ferrous sulphate, which gives a negative image; then pour a solution of potassic cyanide over the plate, and this negative is rapidly converted into a positive.

## VI.

### THE CHEMISTRY OF LUMINOUS FLAMES.

Until a very recent day, all scientific men laid it down as a rule without exceptions, that the light of flames is due to solid bodies or solid particles intensely heated. Frankland, in 1867, was the first to dispute this theory, and to show that there may be very bright flames in which no solid particles are present. He burned a jet of hydrogen in a tube filled with oxygen, and, gradually increasing the pressure upon the gas to twenty atmospheres, he found the brilliancy of the flame to increase with the pressure. At a pressure of ten atmospheres, a burning jet of hydrogen an inch in length gave light enough for reading a newspaper at a distance of two feet from the flame. He also found that carbonic oxide, which usually burns with a very pale flame, burned very brightly under great pressure. In the first case, the product of the combustion was *water*, which must have existed in a gaseous state in the flame: in the second case, the product was *carbonic anhydride*, which must also have been a gas. In both cases, the gas in the flame was rendered more dense by the pressure.

If arsenic be burned in a stream of oxygen gas, it yields a dazzling white flame, though neither the arsenic nor the product of its combination with oxygen can remain solid at the temperature of the flame. The same is true of sulphur and phosphorus when burned in oxygen. The latter burns with a brightness that is almost blinding, and yet the phosphoric anhydride which is produced is so readily volatilized that it can hardly exist as a solid, even at the extreme outer surface of the flame.

These facts, and many others of the same sort, prove that the luminosity of flame may sometimes be due, not to the presence of solid particles, but to that of *dense gases or vapors*, intensely heated. Frankland's experiments appear to show that, as a rule, the denser the vapor the brighter will be the flame. If the pressure of the air upon a flame is increased, it becomes more luminous; if the pressure is diminished, it becomes less luminous. The flame of a common spirit-lamp grows bright in condensed air; and a candle gives more light at the foot of a mountain than at its top, though the rate of combustion is nearly the same in both cases.

Are we to explain the light of an ordinary candle or gas flame in this way? Frankland believes that we should do so. Hydrogen, as we know, has a far greater attraction for oxygen than carbon has; consequently, when both are present, and the supply of oxygen limited, the hydrogen takes up the greater portion of the oxygen to the exclusion of a great part of the carbon. Now, this happens, in the case under consideration, at some little distance within the outer surface of the flame, that is, in the luminous portion; the little oxygen which has penetrated thus far inward is mostly consumed by the hydrogen, and hydrocarbons are separated, rich in carbon and of great density in the state of vapor. These hydrocarbons, which would form smoke if they were cooler, and are deposited as soot\* on a cold body held in the flame become intensely ignited by the burning hydrogen, and evolve a light whose whiteness marks a very

\* Frankland has shown that soot is not pure carbon, but a mixture of heavy hydrocarbons.

elevated temperature. In the exterior and scarcely visible part of the flame, these hydrocarbons undergo combustion.

If the gas be previously mixed with air (as in the Bunsen's lamp), or if air be forced into the interior of the flame, the hydrogen and carbon burn *together*, forming vapors much less dense, and the luminosity almost disappears.

Such, in brief, is Frankland's explanation of the phenomena of ordinary illumination, and the teacher can use it in whatever way he pleases, in connection with the corresponding portions of §§ 192-194, 197, and 199. The new theory appears to be quite generally adopted by scientific men; but no one ought to be ignorant of the old one, which will continue to have at least a historic interest from the fact that it was so long universally accepted as a complete explanation of all the varied phenomena of luminous flames.

It is proper to add that Frankland does not presume to assert that the decomposition of hydrocarbons in the gas-flame is never complete,—in other words, that particles of elementary carbon are never separated,—but he is fully satisfied that “the incandescence of solid particles is not the chief condition of luminosity,” but that the light is “mainly due to the ignition of dense hydrocarbon vapors.”

Certain obvious facts connected with gas-flames are perfectly consistent with this new theory, while they are not easily explained under the old one. The flame from a common fish-tail burner is so transparent that the smallest print can be read through any part of it without the least difficulty. We find, too, that the edge of such a flame gives just as much light as its flat side does. If the light proceeded from solid particles, the most luminous part of the flame ought to be more or less opaque; and, as such particles would obstruct the light of those behind them, the edge of the flame ought to be less bright than the side.

On the whole, we must admit that some of the phenomena of luminous flames can be satisfactorily explained only by Frankland's theory, and that probably it furnishes the correct explanation of nearly all such phenomena.



## VII.

## EXERCISES AND PROBLEMS.

As it is of the greatest importance that the scholar should become, at the start, thoroughly acquainted with the chemical nomenclature and notation, we give below various exercises for practice. We would advise that considerable time be spent upon these before the pupil is allowed to go further with the text.

TABLE I.

$\text{Na}_2\text{O}$	is	sodic oxide.
$\text{Na}_2\text{S}$	„ „	sulphide.
$\text{Na}_2\text{SO}_4$	„ „	sulphate.
$\text{NaCl}$	„ „	chloride.
$\text{NaNO}_3$	„ „	nitrate.
$\text{NaHO}$	„ „	hydrate.

TABLE II.

$\text{BaO}$	is	baric oxide.
$\text{BaS}$	„ „	sulphide.
$\text{BaSO}_4$	„ „	sulphate.
$\text{BaCl}_2$	„ „	chloride.
$\text{Ba}(\text{NO}_3)_2^*$	„ „	nitrate.
$\text{Ba}(\text{HO})_2$	„ „	hydrate.

TABLE III.

$\text{Al}_2\text{O}_3$	is	aluminic oxide.
$\text{Al}_2\text{S}_3$	„ „	sulphide.
$\text{Al}_2(\text{SO}_4)_3$	„ „	sulphate.
$\text{Al}_2\text{Cl}_6$	„ „	chloride.
$\text{Al}_2(\text{NO}_3)_6$	„ „	nitrate.
$\text{Al}_2(\text{HO})_6$	„ „	hydrate.

How many and what elements in sodic oxide?

In baric chloride? In aluminic nitrate?

In sodic hydrate? In baric sulphate?

What element in every compound in the above tables whose name ends in *-ate*?

Does a binary compound ever have this ending to its name?

In what does the name of a binary compound always end?

What element does the ending *-ate* indicate?

Does every compound containing this element have this ending to its name?

\* A figure placed thus after parentheses multiplies all the atoms enclosed therein. Thus  $(\text{NO}_3)_2$  indicates 2 atoms of N and 6 of O.

How many and what atoms in a molecule of sodic chloride?

In sodic sulphide? In aluminic chloride? In baric sulphate?

In sodic nitrate? In sodic sulphate? In baric nitrate?

In aluminic hydrate? In sodic hydrate? In aluminic sulphate?

Each of the compounds in the above tables may be regarded as made up of two parts; namely, a *metal* combined with a single atom or group of atoms. Thus,  $\text{Na}_2\text{O}$  is made up of the metal Na and the non-metal O;  $\text{Na}_2\text{SO}_4$ , of the metal Na and the group of atoms  $\text{SO}_4$ . The metal may be called the *first* part of a compound; and the atom or group of atoms with which it is combined, the *second* part.

What group of atoms in every sulphate?

In every hydrate? In every nitrate?

How many atoms of the metal in a molecule of each of the first three compounds of Table I.?

Of the last three compounds of Table I.?

Of each of the compounds of Table II.? of Table III.?

How many of the second part in a molecule of each of the first three compounds of Table II.? Of the last three of Table II.?

Of the first three of Table III.? Of the last three of Table III.?

Of each of the compounds of Table I.?

H, K, Ag, and Am (ammonium,  $\text{H}_4\text{N}$ ) form compounds like Na. What, then, is the symbol for potassic oxide?

For argentic sulphide? Argentic chloride? Potassic sulphate?

For potassic hydrate? Argentic nitrate? Hydric oxide?

For hydric sulphide? Hydric chloride? Hydric sulphate?

For hydric nitrate? Ammonic hydrate? Ammonic nitrate?

For ammonic chloride? Ammonic oxide? Ammonic sulphate?

For what elements do Sr, Ca, Zn, Pb, Cu, Hg, and Mg respectively stand?

Each of these elements forms a series of compounds exactly like those of Ba. What, then, is the symbol for strontic oxide?

For zincic sulphide? Calcic nitrate? Plumbic sulphate?

For mercuric chloride? Cupric sulphate? Calcic hydrate?

For magnesian oxide? Zincic nitrate? Calcic sulphate?

For plumbic sulphide? Cupric oxide? Mercuric nitrate?

For what elements do the symbols Fe, Mn, and Cr stand?

Each of these elements forms two series of compounds: one like those of Ba; and the other like those of Al. The names of the former end in *-ous*; and those of the latter, in *-ic*.

What is the symbol for ferrous oxide?

For manganic oxide? Ferric sulphide? Chromic nitrate?

Formanganous sulphate? Ferric chloride? Manganic chloride?

For chromous oxide? Ferric sulphate? Ferric nitrate?

For ferrous sulphate? Ferric oxide? Ferrous nitrate?

For manganous oxide? Chromic oxide?

The symbols for the iodides, bromides, and fluorides are written just like those of the chlorides.

What is the symbol for argentic iodide?

For potassic bromide? Calcic fluoride? Ferric iodide?

For ferrous bromide? Ammonic bromide? Hydric iodide?

The symbols of the carbonates are written just like those of the sulphates, the last part being  $\text{CO}_3$ , instead of  $\text{SO}_4$ .

What is the symbol for sodic carbonate?

For ferric carbonate? Calcic carbonate? Potassic carbonate?

For ammoniac carbonate? Plumbic carbonate? Magnesian carbonate?

Correct the following symbols, and give the name of the compound after correction:—

$\text{K}_2\text{Cl}$ ,  $\text{AgO}$ ,  $\text{Ba}_2\text{S}$ ,  $\text{PbI}$ ,  $\text{AlCl}_3$ ,  $\text{NaSO}_4$ ,  $\text{AgI}_2$ ,  $\text{K}_2\text{NO}_3$ ,  $\text{Ca}_2\text{CO}_3$ ,  $\text{Ca}_2(\text{NO}_3)_2$ ,  $\text{Al}_2\text{SO}_4$ ,  $\text{KCO}_3$ ,  $\text{Ag}_2\text{NO}_3$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{AlS}_3$ ,  $\text{Zn}_2\text{O}$ ,  $\text{CuCl}$ ,  $\text{Fe}_2\text{O}$ ,  $\text{FeO}_3$ ,  $\text{Fe}_2\text{SO}_4$ ,  $\text{Fe}(\text{SO}_4)_3$ ,  $\text{FeNO}$ ,  $\text{SrBr}$ ,  $\text{HgCl}$ ,  $\text{Pb}_2\text{SO}_4$ .

What elements form compounds like Na? Like Ba? Like Al?

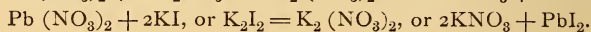
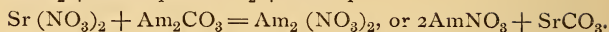
Almost every chemical change is called a *reaction*, but the most common reactions are the changes which take place when the solutions of two substances are mixed. Thus, if we mix hydric sulphate with baric nitrate, the hydrogen and barium change places, and we get baric sulphate and hydric nitrate.

Such reactions can be expressed by *equations*; thus:—



The reaction may be read and explained thus: hydric sulphate and baric nitrate give baric sulphate and hydric nitrate, the hydrogen and the barium changing places.

Read and explain the following reactions : —

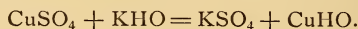


What symbols are wrong in the following reaction?



How many atoms of K and I are needed in the second member of the equation? How many, then, must there be in the first?

Correct the following reaction, and explain the correction : —

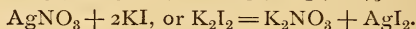
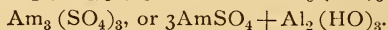
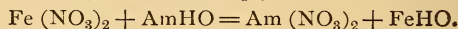


*Ans.* This should be



There must be 2 molecules of KHO, because there must be two atoms of K in the potassic sulphate, and 2 (HO) in the cupric hydrate formed in the reaction.

Correct the following, with explanation : —



Write out and explain the reaction between manganous sulphate and sodic hydrate.

Between manganous sulphate and ammoniac carbonate.

Baric chloride and ammoniac carbonate.

Calcic nitrate and ammoniac carbonate.

Hydric chloride and plumbic nitrate.

Hydric sulphide and plumbic nitrate.

Cupric sulphate and potassic iodide.

Argentiac nitrate and hydric sulphate.

[The teacher can easily multiply these exercises, if he wants more of them.]

## NOTES ON EXPERIMENTS.



### APPARATUS.

The following list includes all the apparatus needed for the more important experiments in this book:—

1. Pneumatic trough.—Gases which are not absorbed by water, or but slightly so, can be collected by first filling the vessel with water, and inverting it with its mouth under water. The tube through which the gas is escaping is introduced under the mouth of the jar, and the gas rises and fills the jar.

For collecting gases in this way, a pneumatic trough is useful and almost indispensable. This apparatus consists of a vessel deep enough to allow of filling and inverting under the water any of the jars ordinarily used. A shelf perforated with holes extends across the vessel about an inch under the surface of the water. After the jar is filled with water and inverted, it is set upon the shelf over one of the holes. The delivery tube (which, except the part passing through the cork, may be of rubber) is then passed into this hole, and the jar filled. It is convenient to have a shelf large enough to hold several jars, after they have been filled with gas.

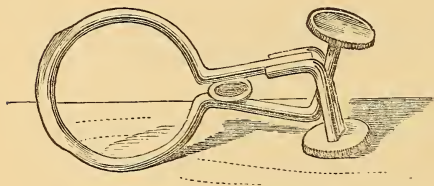
The best pneumatic trough is made of soapstone or copper; but any vessel which will hold water and has a perforated shelf will answer the purpose. The teacher can easily provide himself with such a trough at little expense.

2. Two glass cylinders: one, 1 inch in diameter and 5 inches deep; the other,  $1\frac{1}{2}$  inches in diameter and 7 inches deep. These should have ground mouths and be provided with ground-glass plates for covers.

3. Two two-quart glass jars, with ground mouths and ground plates for covers.

4. Two nipper-taps. A nipper-tap is a convenient substitute for a stop-cock.

Fig. 32.



By means of it a rubber tube can be pinched close. The best kind is shown (full size) in Figure 32. The tube is compressed by a spring.

5. One two-gallon india-rubber gas-bag. This may be closed with a rubber cork, through which passes a short glass tube, connected with a second glass tube by a short piece of rubber tubing, which may be closed with a nipper-tap. Such an arrangement is cheaper than a stop-cock, and better, since gases sometimes corrode the latter.

6. A bottle generator. This consists of a wide-mouthed pint bottle, closed with a rubber cork, through which pass two tubes; one, large and straight, and passing nearly to the bottom; the other, small, and bent at right angles, passing only through the cork. An ordinary cork will answer, but rubber corks are always to be preferred for chemical apparatus. They cost more at first, but they last much longer, and make perfectly tight joints.

7. Three half-pint flasks. One, at least, of these should have a rubber cork through which passes a bent delivery-tube.

8. An iron lamp-stand with three rings.

9. A lamp. A Bunsen's lamp is much to be preferred where gas is to be had; otherwise, an alcohol lamp.

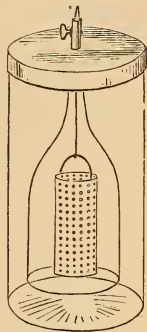
10. A wooden retort-holder with two clamps.

11. A hydrogen generator. The most convenient apparatus for preparing hydrogen is the self-regulating generator shown in Figure 33. It consists of a glass vessel closed with a metallic cap. A bell-shaped glass vessel, open at top and bottom, is fastened to this cap by an air-tight joint. A tube closed by a stop-cock passes through the cap into the bell-shaped vessel. A copper bucket perforated with fine holes is hung from a hook



inside this vessel. This bucket is filled with shreds of sheet zinc or bits of granulated zinc. The outer vessel is filled about two-thirds full of dilute sulphuric acid (the ordinary oil of vitriol diluted with about ten parts of water). The metallic cap with the bell-glass attached is then put in its place, and the stop-cock opened. The air is first driven out, and the dilute acid coming in contact with the zinc begins to act upon it, and hydrogen is given off in abundance. When sufficient hydrogen has been obtained, the stop-cock is closed, the hydrogen generated collects in the upper part of the bell-glass, and drives the acid out. As soon as the acid is driven out, the action ceases until the stop-cock is opened again, and the hydrogen allowed to escape. By means of rubber tubing, the hydrogen can be conveyed from the generator to the jar or vessel in which it is to be collected. When hydrogen is to be burned, the greatest care must be taken that all the air is driven out of the apparatus before the gas is collected.

Fig. 33.



12. A chlorine tube. This is a glass-tube,  $\frac{3}{4}$  of an inch in diameter, and 15 inches long, closed at one end. The other end should be provided with a rubber cork, through which passes a glass tube drawn out to a fine jet inside. This should be connected with a small glass funnel by means of a short piece of rubber tubing, which may be closed by a nipper-tap.

13. Two small beakers.

14. Two evaporating dishes.

15. A U-tube (Figure 5). One end of the tube should be closed, and near this closed end two platinum wires should pass through the sides so as nearly to meet within. These wires should terminate outside in loops. It is not necessary that the U-tube should be tubulated at the bend, as represented in the figure, or fastened to a stand, since it may be held in the clamp of the retort-holder.

16. A chalk cup. This is a cylinder of chalk, about  $1\frac{1}{2}$  inches in diameter and 2 inches high, hollowed out at the top.

17. A wash-bottle. This is like No. 6. The rubber tube which

is delivering the gas should be connected with a glass tube small enough to pass down through the straight glass tube to the bottom.

18. A nitric-oxide bell and jar. The bell is half the capacity of the jar, and the mouths of both are ground, so as to fit together air-tight.

19. An asbestos tube.

20. A half-pint tubulated retort.

21. A dozen 5-inch test-tubes.

22. Half a pound of glass tubing,  $\frac{1}{4}$  of an inch in diameter.

23. 4 feet of rubber tubing,  $\frac{1}{4}$  of an inch in diameter.

The following additional apparatus will be needed for experiments with the oxy-hydrogen blowpipe:—

Two 25-gallon gas-bags, with stop-cocks and tubing.

An oxy-hydrogen jet.

A copper flask for making oxygen.

## EXPERIMENTS.

1. (§ 1, *Exp.* 1.) Use bottle generator (No. 6 in list of apparatus above). The end of the long tube must be kept beneath the surface of the acid. The acid is diluted with 2 or 3 parts of water. The hydrogen may be collected in the small glass cylinder (No. 2); but the gas which first comes off must not be collected, as it is mixed with air, and therefore explosive.

2. (§ 1, *Exp.* 2.) Use flask (No. 7) with rubber cork. Pour in strong muriatic acid first, so that none of the dry manganese may stick to the flask. Use only a small quantity of the materials, as the chlorine is very disagreeable if it escapes into the room. It is well to have a large jar filled with water, ready to receive any chlorine that may come off after the small cylinder has been filled. It will be well also to let the gas which first comes off pass into this jar until the air is expelled from the flask. The flask should be supported on the ring of the lamp-stand (No. 8), and should be separated from the flame, either by a sand-bath or, better, by a piece of fine wire gauze.

3. (§ 1, *Exp.* 3.) Use the smaller glass cylinder (No. 2). Let the hydrogen pass in first until it is half full, and then fill

the remainder with chlorine. Close the cylinder under water with the glass plate, bring it near the lamp, remove the glass plate, and quickly put the mouth of the cylinder into the flame. The explosion is not very violent with these small quantities. Never attempt to use large quantities, and be careful to keep the mixed gases out of direct sunshine.

Another way of performing the experiment is to use two cylinders of the smaller size (No. 2), filling one with hydrogen and the other with chlorine. Cover them with the glass plates, and place them together, mouth to mouth, as represented in Figure 34. Then withdraw the glass plates, keeping the mouths of the cylinders together, shake the cylinders to mix the gases, and open them over a burning lamp, as shown in Figure 35.

Fig. 34.

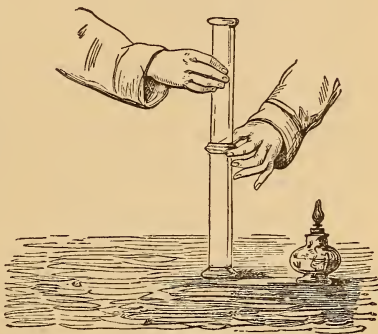


Fig. 35.



4. (§ 2, *Exp.* 1.) The sodium used must be pure, else there is danger of an explosion. The smaller cylinder (No. 2) must be used and held in the clamp of the retort-holder (No. 10). The sodium may be first thrown upon the water, and then thrust under the cylinder by means of a perforated metallic cup, which may be made out of a thimble by punching a few holes through the top, and fastening a wire round it for a handle.

5. (§ 2, *Exp.* 2.) The water may be saturated with chlorine by putting it in a wash-bottle (No. 17), and allowing the chlorine to pass through it as long as it is taken up by the water.

The delivery-tube of the bottle should be connected with a jar over the water-trough, in order that no chlorine may escape into the room. The chlorine water thus prepared may be put in the larger cylinder (No. 2), inverted in a soup-plate of water, and set in the sunshine.

6. (§ 2, *Exp.* 3.) Fill one of the jars (No. 3) with oxygen, and let it stand over the trough long enough to drain. Burn the hydrogen as it escapes from the generator (No. 11) through a glass tube bent at right angles and drawn out to a fine jet; and hold the jar of oxygen over the flame.

Glass tubing may be bent by heating it red-hot in the flame of the lamp. A tube may be drawn out to a fine jet by heating the middle red-hot, and then quickly pulling the ends apart. It may be cut by scratching it a little on one side with a three-cornered file, and then bending it over the thumb-nails, held close together on the side opposite the scratch.

7. (§ 3, *Exp.* 1.) Fill chlorine tube (No. 12) with chlorine over the water-trough. Close the mouth while under water with the thumb, invert it, and insert the cork. Pour a little strong ammonia into the funnel, and let it drop slowly into the tube by means of the nipper-tap, to the depth of half an inch. Close the nipper-tap, and pour off the ammonia from the funnel; and then fill the funnel with water, and let it run into the tube, care being taken to keep water in the funnel all the time, so that no air may get into the tube.

In this and all other cases where chlorine is to be used, it will be best to prepare it beforehand, and keep it in a gas-bag till wanted. On its way from the generating flask to the gas-bag, it should be passed through a wash-bottle containing a small amount of water. The gas is washed to remove any muriatic acid which may be in it, and which would corrode the bag.

8. (§ 6, *Exp.* 1.) Fill the bent tube in the first place with water, close it with the thumb, and invert it over water. Then allow a little hydrogen to pass into it from the generator, and also some oxygen from a gas-bag which has been previously filled with this gas. With a little care, one can readily get the right proportions. The tube should not be more than two-thirds full of the mixed gases, and a considerable excess of one

gas should be used, so that enough may be left for testing. After putting the gases into the tube, close it with the thumb, raise it from the water, and tip it so that the gases may pass into the closed arm; then pour out a little of the water, and again close it with the thumb. Connect the outer coating of a charged Leyden jar with one of the platinum loops, by means of a wire or chain, and bring the knob of the jar in contact with the other loop. After the spark has passed, again fill the open arm with water, close it with the thumb, and tip the tube so as to transfer the remaining gas to the open arm, and there test it.

9. (§ 10, *Exp.* 1.) As explosions sometimes occur in the manufacture of oxygen, care should be taken that the chemicals are pure; and it would be well to test each purchase by putting some of the potassic chlorate in an iron spoon and heating it over a spirit lamp until it is melted; then stir into it with an iron wire some of the black oxide of manganese; and if these materials are not good, an explosion will take place, and a whitish mass with red spots in it will be left in the spoon. If, however, the chemicals are pure, there will be no explosion, and the melted mixture will soon dry up, leaving a dark gray residuum. If the bubbles come over too violently, remove the lamp for a few minutes until they come more moderately.

A glass flask may be used; but as it is liable to break, a copper flask may perhaps be found cheaper in the long run, especially if one has to make oxygen often.

10. (§ 11, *Exp.* 1.) Use glass jar (No. 3). The charcoal may be fastened to a piece of wire and ignited in the flame of a lamp. It is well to have the other end of the wire attached to a copper or wooden disk, which serves to cover the jar while the charcoal is burning.

Lime-water may be made by putting a small quantity of slaked lime into a jar (No. 3) of water, stirring it thoroughly, and allowing it to settle. The clear liquid may then be poured off into a bottle, and kept for use.

11. (§ 11, *Exp.* 2.) Fill a jar (No. 3) with oxygen, and let it stand to drain. Put a piece of sulphur in the chalk cup (No. 16), ignite it by touching it with a red-hot wire, and invert a jar of oxygen quickly over it. The jar should be kept closed

with the plate until it is inverted, and brought just over the sulphur. The chalk cup should stand in a shallow dish of water, so that the mouth of the jar may dip under the water and prevent the  $\text{SO}_2$  from escaping into the room.

12. (§ 11, *Exp.* 3.) The phosphorus may be burnt in the same way as the sulphur. As phosphorus is a very inflammable substance, and as burns from it are very slow to heal, great caution must be exercised in using it. The sticks must always be cut under water, and it must be carefully dried, by pressing it between pieces of unsized paper, before it is burnt; else it will fly about in a very disagreeable and dangerous manner. It should always be lighted by touching it with a heated wire, never by holding it in the flame of a lamp.

13. (§ 11, *Exp.* 4.) The watch-spring should be either straightened out or formed into a spiral, and fastened to a disk of copper or wood, as above described. Water should be left in the bottom of the jar to the depth of two inches or so, that the melted globules of iron may not burn into the jar.

14. (§ 12, *Exp.* 1.) Ozone may be most easily prepared by pouring a little ether into a jar (No. 3), and then when the air in the jar has become saturated with the vapor of ether, stirring the air with a glass rod heated nearly to redness.

15. (§ 20, *Exp.* 1.) In making hydrogen, use the hydrogen generator (No. 11).

16. (§ 21, *Exp.* 1.) Mix the gases in the gas-bag, letting each gas pass in separately. The quantities can be estimated nearly enough by the eye. Fasten an ordinary clay tobacco-pipe to the gas-bag, hold the mouth of the pipe in soap-suds, and press out the mixed gases in a gentle stream. For obvious reasons, the nipper-tap should be closed before the bubbles are lighted.

17. (§ 28, *Exp.* 1.) Fill the bottle generator (No. 6) one-third full with strong ammonia, and connect the large tube with a rubber bag filled with chlorine. Connect the delivery-tube with the wash-bottle (No. 17), and the delivery-tube of the wash-bottle with the larger cylinder (No. 2). Force the chlorine through the apparatus by compressing the bag. Care must be taken not to force an excess of chlorine through the ammonia,



lest the very explosive *nitric chloride* (page 28) be formed. There is little danger, however, if *strong ammonia* is used.

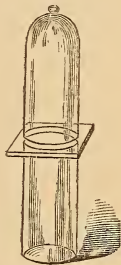
18. (§ 30, *Exp.* 1.) Use the bottle generator (No. 6). First pour in water enough to cover the bits of copper (brass or nickel will do as well), and then pour in gradually strong nitric acid. The gas is very poisonous, and should not be allowed to escape into the room.

19. (§ 30, *Exp.* 2.) The management of the experiment is the same as in the burning of phosphorus in oxygen (12).

20. (§ 30, *Exp.* 3.) The gases may be mixed in a gas-bag. It is not necessary that the proportions should be exact.

21. (§ 33, *Exp.* 1.) Use nitric-oxide bell and jar (No. 18). Fill the bell with oxygen, and the jar with nitric oxide. The jar should be closed with a plate and set on the table, and the bell of oxygen set on the plate covering the jar (Figure 36). When the experiment is to be tried, the plate should be drawn out, and the mouths of the bell and jar allowed to come together.

Fig. 36.



22. (§ 36, *Exp.* 1.) Use tubulated retort (No. 20). Only a small quantity of the ammonic nitrate need be used. The retort must not be heated too much, lest the gas should come off with explosive violence.

23. (§ 37, *Exp.* 1.) Gases, like ammonia and muriatic acid, which are absorbed by water, must be collected over mercury.

For the experiments of this book we think a mercury-trough a needless luxury. An evaporating dish of Berlin porcelain answers every purpose. One five inches in diameter is large enough to use with the cylinders mentioned above. It should be set in a shallow dish of strong glass or earthen ware, to prevent loss of mercury in case of accident. It should then be filled nearly full of mercury. The cylinder to be used is next filled with mercury to the brim. The ground-glass cover is then placed on the mouth of the cylinder and held firmly with the right hand, the cylinder inverted, and its mouth plunged beneath the mercury in the evaporating dish. It is well to put the cylin-

der in a strong dish when you are filling and inverting it, to save any mercury which may be spilled. After the cylinder is filled and inverted over the mercury in the dish, the plate is slipped from its mouth, and the cylinder is securely fastened in the clamp of a retort-stand, so that its mouth is held about  $\frac{1}{2}$  or  $\frac{3}{4}$  of an inch above the bottom of the dish.

To fill the cylinder with ammonia gas, a little aqua ammonia is put into a flask provided with a delivery-tube, and gently boiled. To the delivery-tube is attached a piece of rubber tubing to connect it with the cylinder. A short piece of glass tubing with its end slightly turned up must be fastened to the end of the rubber tube, so that the gas may be introduced into the cylinder through the mercury. On first boiling the aqua ammonia, a large amount of air passes over from the flask. The ammonia gas must not be collected until this has all passed over. To determine when this has taken place, put the glass tube at the end of the rubber tube into a vessel of water; when heat is first applied to the flask, bubbles of gas will rise from the end of the tube through the water as long as any air comes over. When the air is all over, the ammonia gas is absorbed by the water as fast as it comes over, and no bubbles rise to the surface. After the air ceases to come over, plunge the end of the glass tube into the mercury, and introduce it under the mouth of the cylinder. The gas will rise into the jar and displace the mercury.

Fig. 37.



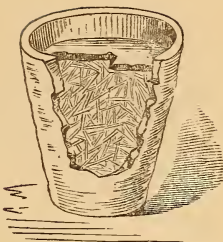
When the cylinder is filled with ammonia, close it with a glass plate, and remove it to a vessel of water; then open the mouth of the jar under the water (Figure 37).

24. (§ 43, *Exp.* 1.) The oxalic acid may be heated with sulphuric acid in a flask, and the solution of soda put in a wash-bottle.

25. (§ 45, *Exp.* 1.) In both experiments, the sulphur should be heated cautiously, that it may not

take fire. Figure 38 shows the needle-shaped crystals which may be obtained by the first experiment.

Fig. 38.



26. (§ 53, *Exp.* 1.) With the aid of an air-pump, phosphorus may be burnt in chlorine in the following manner: Place the chalk cup, with a bit of phosphorus in it, on the bottom of the nitric-oxide jar (No. 18), and cover the jar with a well-fitting glass plate which has in its centre a round hole,  $\frac{3}{4}$  of an inch in diameter. This hole is closed with a rubber cork, through which passes a glass tube connected with a second glass tube by a short piece of rubber tubing provided with a nipper-tap. Connect the jar with the air-pump by rubber tubing, and exhaust the air. Close the nipper-tap, and connect the jar with a gas-bag filled with chlorine. Open the nipper-taps, and let the chlorine pass into the jar, until the pressure within is nearly but not quite equal to that outside. The phosphorus will soon take fire. If the jar were filled full of chlorine, the heat of the burning phosphorus would expand the chlorine, and force out some of it into the air.

27. (§ 60.) The color of iodine vapor may be shown by heating a few grains of iodine in a flask over the lamp.

28. (§ 65, *Exp.* 1.) Use tubulated retort (No. 20). Fill it nearly full of water, put in a small piece of phosphorus, and let the mouth of the retort dip under water. Heat the retort until the water in it boils, and then drop in a stick of caustic potash through the tubulature. The water is boiled first in order to drive out the air from the retort, so that the hydric phosphide may not take fire inside, and thus cause an explosion.

29. (§ 123, *Exp.* 1.) The process is the same as in the experiment in § 33, using air instead of oxygen.


30. (§ 123, *Exp.* 2 ) Observe the precautions given in § 12.

31. (§ 142, *Exp.* 1.) The sugar and the potassic chlorate should be pulverized separately, and then mixed carefully. Put the mixture on an earthen dish, and let one drop of sulphuric acid fall upon it from the end of a long glass rod. The experiment is brilliant, even with much smaller quantities.



## QUESTIONS FOR REVIEW AND EXAMINATION.



 *The numbers refer to the sections of the book.*

THE NON-METALLIC ELEMENTS. — 1. Describe the experiments with muriatic acid. What products are obtained? The test for each? How may they be united again? 2. Describe the experiments with sodium and chlorine water. What are obtained? How is the oxygen tested? If hydrogen be burnt in oxygen, what is the product? What does this show? 3. Describe the experiment with ammonia. What new gas is obtained, and how is it tested? What does ammonia contain? 4. Define compounds and elements. Give examples of each. How many elements? 5. What two classes of elements? What are symbols? What is the symbol of gold? of iron? Explain. 6. What is affinity? What are its three characteristics? Illustrate each. 7. What are molecules? atoms? Why so called? What is said of the atoms of an element? What of the molecules of a compound? What is this theory called? What is the atomic constitution of muriatic acid? of water? of ammonia? 8. What symbols do compounds have? What is indicated by these symbols? Illustrate. 9. What are atomic weights? The atomic weight of H? of O? of N? of Cl? How is the relative weight of the elements in a compound shown by the symbol? 10. Describe the preparation of O from  $\text{KClO}_3$ . What is a reaction? Express this reaction by an equation, and explain in full. 11. Describe experiments with charcoal, sulphur, and phosphorus. What product in each case? How may Fe be burnt in O? What product? What properties of O do these experiments illustrate? 12. What is ozone? Why so called?

## 198 QUESTIONS FOR REVIEW AND EXAMINATION.

How obtained? How tested? 13. What are allotropic states? 14. What are oxides? How named? 15. What are acid oxides? anhydrides? acids? Illustrate. Explain the names and symbols of acids. 16. What are basic oxides? bases? How named? Illustrate. What are alkalies? 17. What are neutral oxides? 18. What is a salt? How named? Illustrate. 19. What are binary compounds? ternary compounds? 20. How is H prepared? Express the reaction in an equation, and explain it. 21. What are the properties of H? Illustrate by experiments. 22. Describe the oxy-hydrogen blowpipe, and the experiments with it. What is the lime light? 23. The properties of  $\text{H}_2\text{O}$ ? What is said of its solvent power? 24. What is said of rain water? spring water? mineral waters? hard and soft water? sea water? 25. What is said of  $\text{H}_2\text{O}$  in plants and animals? 26. What is water of crystallization? Efflorescence? Deliquescence? 27. Give some account of the uses of  $\text{H}_2\text{O}$ . 28. How is N prepared? 29. The chief characteristic of N? 30. How is NO prepared? What experiments with it? 31. Define catalysis. 32. What is meant by the nascent state? 33. What is  $\text{N}_2\text{O}_3$ ? How prepared? 34. What is  $\text{NO}_2$ ?  $\text{N}_2\text{O}_5$ ?  $\text{HNO}_3$ ? 35. The properties of  $\text{HNO}_3$ ? How made? Illustrate by an equation. Explain the action of  $\text{HNO}_3$  on metals? 36. What is  $\text{N}_2\text{O}$ ? How made? Its properties and uses? 37. What is  $\text{H}_3\text{N}$ ? When absorbed by water, what does it form? How is it prepared? 38. What is ammonium? Why is it considered a metal? 39. What is CN? How obtained? For what remarkable? What are some of its compounds? What are radicals? 40. What are the characteristics of N? Illustrate each. 41. Describe the allotropic forms of C. 42. What is  $\text{CO}_2$ ? Its properties? How prepared? Explain. How tested? 43. What is CO? Its preparation? Properties? 44. What are the sources of S? How is it purified? 45. Describe the allotropic forms of S. Its properties? 46. What is  $\text{SO}_2$ ? Properties and uses? Illustrate by experiment. 47. What is  $\text{H}_2\text{SO}_4$ ? Ways of making it? Explain in full. 48. What is  $\text{SO}_3$ ? Properties? 49. What is  $\text{H}_2\text{S}$ ? Preparation? Properties and uses? 50. What is  $\text{CS}_2$ ? How made? Properties? 51. What elements belong to the O group? Why thus classed? 52. How is Cl prepared? Explain



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ing the daily consumption of O. 145. Describe the formation of the embryo plant in the seed. 146. Give an account of the growth and structure of the plantlet. 147. What are organic beings? What is organic structure? 148. Explain how plants get their food. 149. Of what does the inorganic portion of the plant consist? Why are manures necessary in agriculture? Why are fields allowed to lie fallow? Explain the principle of the alternation of crops. 150. Give an account of the organic portion of the plant. 151-153. How does the plant get H and O? C? N? 154. Show that the growth of plants is a chemical process, and how it is carried on. 155. Show that plants purify the air for animals to breathe. 156. Show that plants prepare food for animals. 157. What is said of the relations of plants and animals? 158. Give a full account of starch. 159. What is sugar? What two kinds? 160. What is the symbol for cane-sugar? From what is it obtained? Describe its manufacture from the cane, and the refining process. Give some facts in the history of sugar. 161. What names has  $C_{12}H_{24}O_{12}$ ? In what is it found? How may it be made? Its uses? 162. What are the sources and uses of dextrine? 163. What is the symbol of cellulose? How is gun-cotton made? What is said of it? What is collodion? Its uses? 164. Describe the manufacture of vegetable parchment. Its uses? 165. What is said of  $C_4H_6O_6$ ? of its compounds? What is  $C_6H_8O_7$ ?  $C_4H_6O_5$ ?  $C_2O_3$ ?  $H_2C_2O_4$ ? Give an account of tannic acid and tannin. 166. What is the composition of fats and oils? What two classes of oils? Give some account of both. 167. What is soap? How do hard and soft soap differ? The composition and uses of glycerine? 168. What is said of wax? 169. How do gums and resins differ? Mention the chief examples of each. 170. Give some account of vegetable alkaloids. 171. Describe the proteine bodies? Why are they important?

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For concise statements of the leading topics of the book, see the **SUMMARIES**, which will be readily found by means of the *Table of Contents*. The references in this Index are only to the fuller treatment of subjects in the body of the work.

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